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WORKS OF THE INTERVUZ SCIENTIFIC CONFERENCE ON THE PROBLEMS OF CONSTRUCTING A GEODETIC CONTROL NET

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Prof. and Doctor of Technical Sciences K. Provorov,
Chairman of the Organizing Committee

(Novosibirsk, 26-30 October 1959.)

In order to fulfill the grand tasks established by the XXI Congress of the Communist Party of the Soviet Union directed toward the building of Communism in our country, geodesists and cartographers are to carry out a great number of varied and complex projects, primarily in the eastern regions of the USSR.

A topographical study of the land, which is essential to the solution of many national economic problems, and also problems of the defense of the nation require the establishment of a highly accurate geodetic net, which is of great scientific importance along with its economic value. Therefore great attention should be devoted to improving the planning and the program for the development of this network along with improving the techniques of measurement in constructing a state geodetic net.

Soviet geodesists and cartographers can take pride in the fact that the successful development of geodetic projects in our country is linked with the name of the great Lenin, who signed the decree on the organization of the State Cartographical and Geodetic Service. In the 40 years that have passed since that day, geodetic projects have been fulfilled which are outstanding in their size and quality. The number of links in the astrogeodetic net has reached 500 and over two thirds of the area of the USSR is covered by the polygons of this network, which has created conditions for establishing a single system of coordinates and surveys for the entire territory of the Soviet State. This astrogeodetic network has no equal in the world in its quality and uniformity. In the last 10 years Soviet geodesists have undertaken the construction of dense triangulation nets of high accuracy over large areas.

Our geodesists, who enjoy the constant support of the Soviet government and who are headed by an outstanding scientist, Professor F. N. Krasovskiy, have obtained measurements of the earth which are more reliable than any ever made previously and which are accepted today in many countries.

Contemporary achievements in different branches of science and technology, in the first instance in the fields of electronics, radio engineering, and automatic devices, have brought about new methods of measurement which have compelled a new approach not only to technical but also to administrative problems of constructing a state geodetic net.

These achievements in the field of geodetic measurements include optical and radio range finders, as well as attachments which make possible a considerable increase in the accuracy of angular measurements. The work of our scientists and production people on problems of the mathematical processing of the results of geodetic observations should also play an important role.

Soviet geodesists are faced with new problems in the field of constructing a state geodetic net in connection with problems of the further study of the shape of the earth and horizontal and vertical movements of the earth's crust. There is no doubt that improvement of the state geodetic net is essential to the objectives of strengthening the defense capabilities of our Motherland.

The Scientific Conference of Higher Educational Institutes has resolved in respect to the construction of a state geodetic network:

1. To consider that the development of plans and a program for a state geodetic network is of decisive importance in setting up geodetic projects which will fully ensure the solution of production, defense, and scientific problems.

2. To consider as the first priority task the completion in the current Seven-Year Period of an astrogeodetic net over the entire territory of the Soviet Union in the form of polygons, observing the conditions and requirements formulated in the Fundamental Propositions of 1954 and taking into account the fullest utilization of contemporary means for making high-precision linear measurements.

3. The most important problem is the construction of a high-accuracy dense network of control points inside the polygons of the astrogeodetic net. In order to make these networks truly fundamental and precise so that they will not have to be done over again in the near future, the measurements of these networks must be made with the maximum accuracy possible in mass field projects with the existing instruments.

In connection with the appearance of new means for making measurements in the form of radio and optical range finders, accurate polygonometry should acquire corresponding development.

In all cases it will be necessary to ensure a density in the state geodetic network such that there will be one point in not more than 50 square kilometers. In regions of difficult access (impassable bogs and mountains whose tops are perpetually covered with snow) it will be necessary to construct nets of triangles with longer legs.

4. To consider it to be one of the principal tasks of scientific and production personnel to work out concrete plans for construction of a state geodetic network for large-scale topographical surveys, depending on general scientific and technical requirements, the physical geographical conditions in the regions, the prospects of their national economic development, always taking into account the experience which has accumulated in production work.

In working out such plans it is essential to endeavor to reduce as far as possible the number of steps in their development. The development of plans should be accompanied by objective technical and economic motivation.

5. The Conference recommends an examination of the question of the systematic conduct of repeated observations at points of the state geodetic net with the objective of studying movements of the earth's crust.

6. Taking into consideration that optical and radio range finders are progressive tools of a new technology, the Conference requests that the Ministry of Higher and Secondary Special Education USSR submit a petition to the Gosplan USSR and to the State Committee on Electronics on expediting the series production of these instruments.

7. It is essential to continue and to expand the development of new means for geodetic measurements and the mathematical processing of the results obtained from the field, at the same time making maximum use of contemporary achievements in the field of automation and mechanization.

At the same time, too, measures must be taken to improve existing designs for high-precision geodetic instruments and devices.

8. The Conference considers it essential to ensure the possibility of making field tests of new methods for adjusting large geodetic networks.

9. As for the training of geodetic cadres, the Conference wholly approves and supports the measures put into effect recently to strengthen the training of students in the fields of mathematics and physics and also in broadening field practice work.

At the same time, it is necessary to devote more attention to replenishing geodetical departments and to ensure a sharp decrease in the subsequent screening of specialists. It is requested that the GUGK [Glavnoye Upravleniye Geodezii i Kartograffi -- Main Administration of Geodesy and Cartography] of the Ministry of the Interior USSR and the aerogeodetic enterprises adopt all pending measures to send young workers who have done well in field work to geodetic establishments of higher learning.

10. In the interests of raising the scientific and technical level of engineering and technical personnel in field work, it is considered expedient to ensure the systematic conduct of course work on the study of modern achievements in geodetic science and techniques in the geodetic establishments of higher learning.

11. The Conference considers it necessary to create proper conditions for conducting scientific research projects in geodesy and topography in Siberia and recommends an examination of the question of organizing a branch of the TsNIIGA iK [Tsentral'nyy Nauchno-Issledovatel'skiy Institut Geodezii, Aeros'yemki i Kartografii -- Central Scientific Research Institute of Geodesy, Aerial Surveying and Cartography] in Novosibirsk and a geodetical laboratory under the Novosibirsk Branch of the Academy of Sciences USSR.

II. THE TASKS OF THE GEODETIC SERVICE IN FULFILLING THE SEVEN-YEAR PLAN FOR THE DEVELOPMENT OF THE NATIONAL ECONOMY OF THE USSR

Pages 9-15

A. N. Baranov, Chief of
the Main Administration
of Geodesy and Cartography,
Ministry of the Interior
USSR

The Twenty-First Congress of the Communist Party of the Soviet Union summed up the great victories of the Soviet people with deep satisfaction and revolutionary pride. The greatest achievement of the heroic struggle and labor of the Soviet people is the new society they have created - socialism, and the political structure corresponding to it - the Soviet socialist state.

Our country has become a mighty socialist power with a highly-developed economy and advanced science and culture. At present the USSR occupies first place in Europe and second place in the world in total production. The following vital gains in the national economy were noted in the resolutions: The gross production of industry increased 36 times over the 1913 level, the production of the means of production grew 83 times, and metalworking and machine manufacture increased 240 times. In 1958 labor productivity had increased to 10 times the 1913 level, and this was accomplished with a marked reduction in the working day (as compared with 1913).

In the years of the Soviet regime the per capita income increased 15 times. The plan for 1958 was successfully fulfilled by all branches of the national economy and the plan for 1959 is being successfully fulfilled. In 1958 industrial production increased 10 percent as compared with the 7.6 percent growth specified in the plan.

In 1958 the nation produced: 55 million tons of steel, 113 million tons of oil, and 233 billion kilowatt-hours of electric power, that is, more steel and oil were produced in one month than for the whole of 1913, and as much electric power was produced every 3 days as was produced in a whole year in the old Russia. In 1958, capital investments amounted to 235 billion rubles, that is, more than were invested in the First and the Second Five-Year Plans put together.

State topographical and geodetic projects and the cartographical industry have also seen significant development. A topographical survey of the entire territory of the USSR on the basic state scale (1:100,000) has been completed, a large geodetic control network has been developed, and large-scale surveys have been developed on a wide front. The amount of triangulation work has increased 2.5 times over the 1940 level; level surveying of the first and second order, 3.6 times; topographical surveys, 4.7 times; and gravimetry, more than 2 times.

Our country is entering a new period in its development - the period of large-scale building of a Communist society. The chief tasks of the forthcoming Seven-Year Plan, as noted in the resolutions of the XXI Congress are: in the field of economics - to take a decisive stride forward in creating the material base of Communism and in ensuring the victory of the USSR in peaceful economic competition with the capitalist nations; in the field of politics - to secure the further strengthening of the Soviet socialist order, the over-all strengthening of the union of workers and peasants, and the friendship of the peoples of our country; in the field of ideology-- to intensify the ideological and indoctrination work of the Party, to increase the Communist consciousness of the working people and, first of all, the young generation, to overcome the surviving remnants of capitalism in the minds of the people, and to carry on the struggle against bourgeois ideology; and in the field of international relations - to maintain and to strengthen peace on the basic of Lenin's principle of the peaceful co-existence of nations with different social systems.

The XXI Congress instructed us: "In order to make the most rational use of capital investments, it is essential to direct large sums into the reconstruction, expansion, and technological re-equipping of existing enterprises, rebuilding and modernizing machinery, all of which will make it possible to solve the problem of increasing production and raising labor productivity with smaller outlays and more rapidly than investing in the construction of new enterprises.

"Bearing in mind the unheard-of scale of construction in the forth-coming Seven-Year Plan and the necessity for achieving the maximum economy of socialized labor and time, it is essential to devote special attention to the proper disposal of the productive forces.

"It is necessary to direct attention to the further development of the economics of the eastern regions of our country which possess enormous natural resources.

"In solving the problems of the further development of our resources, preference should be given those regions where the investment of funds will have the greatest economic effect."

In accordance with this, the Seven-Year Plan stipulates that the eastern part of the nation should produce: up to 50 percent of the total coal production, up to 48 percent of all the steel produced, up to 88 percent of all the copper, up to 71 percent of all the aluminum, up to 42 percent of all the cement, up to 46 percent of all the electric power, up to 52 percent of all the wood, and up to 32 percent of all the paper. New industrial centers are to be created: the Kustanay, Pavlodar-Ekibastuz, Achinsk-Krasnoyarsk, Bratsk-Tayshet, and others, which will radically change the economic picture of the East and give a mighty impetus to the development of the productive forces of the eastern regions. A new grain-producing base has been created in the East. The use of ores from the Kursk Magnetic Anomaly and the Krivoy Rog Area is being expanded.

The distribution of topographical and geodetic projects should correspond completely with the distribution of the productive forces of the nation. The Seven-Year Plan for the Geodetic Service was compiled in accordance with the decisions of the XXI Congress of the CPSU and is closely connected with the development of the productive forces of the USSR and their distribution. Up to 80 percent of all the capital outlays of the GUGK are to be spent on the eastern regions of the nation.

The prospective plan for the development of topographical, geodetic, and cartographical work in 1959-1965 has been worked out. The principal tasks of the 1959-1965 plan are:

1. To satisfy the first-priority requirements of the national economy of the USSR in respect to topographical maps on scales of 1:25,000 and 1:10,000.
2. Completion of work on the establishment of an astrogeodetic network and the state altitude basis for the USSR.
3. Supplying the schools of the USSR with educational maps and stable atlases.
4. Setting up large cartographical projects.
5. Supplying the developing topographical and geodetic projects with the newest and most productive geodetic and stereophotogrammetrical devices and instruments.

Accordingly, the draft of the prospective plan for 1959-1965 stipulates:

THE CONDUCT OF TOPOGRAPHICAL AND GEODETIC PROJECTS

The planned volume of topographical and geodetic projects in 1965 is to be increased over the 1958 level in the following amounts:

	In 1965 (in percent of the 1958 level)
I. The volume of topographical and geodetic work in estimate prices - total	169.5
Which includes:	
a) Topographical and geodetic projects	172.0
b) Cartographic work of national importance	117.8
II. The most important types of topographical and geodetic projects:	
a) Triangulation, classes 1, 2 and 3	153.2
b) Level surveying, classes I, II, and III	161.5
c) Gravimetry, classes I, II, and III	136.8
d) Aerial photography	146.2
e) Topographical maps on scales of 1:25,000 and 1:10,000	160.7
f) Preparation of topographical plans for publication	131.4

III. Topographical and geodetic projects fulfilled on contract for different departments 200.0

It may be seen from the data presented here that the prospective plan provides for a marked increase in the volume of work to be done in 1965 as compared with the 1958 level. At the same time, this growth is to be distributed evenly over the years. This increase in the volume of topographical and geodetic work is essential to meeting the growing requirements of the national economy of the USSR in respect to topographical maps and meeting the needs of the defense of the nation.

In taking up the question of the distribution of topographical and geodetic projects in the forthcoming Seven-Year Plan, it is necessary to note the following regions:

a) Completion of topographical surveys of the Urals.

b) The regions adjoining the Urals on the east. These regions are of interest in that data obtained by geophysical prospecting indicate the presence of large reserves of natural gas there. In this connection, the Seven-Year Plan calls for the construction of a gas pipeline from Salekhard to Sverdlovsk.

c) Regions of virgin lands which have been broken and which are being broken, and fallow lands.

d) The regions of the lower and the middle reaches of the Angara River, called the Angaro-Pitsk Region in N. S. Khrushchev's speech, where very rich deposits of iron ore and also polymetallic ore deposits have been discovered.

e) The regions of very rich coal beds, which have received the name of the Tungus Coal Beds, located north of the Angaro-Pitsk Region.

f) The Krasnoyarsk-Achinsk Region where a great amount of construction is planned.

g) The regions of the Yakutsk Diamond Development and the Yuzhno-Yakutsk Coal Basin.

h) The regions of the mouth of the Vilyuy River and the Vilyuy Lowlands where industrial reserves of oil and natural gas have been discovered, and also a number of regions of the Far East.

Over a million square kilometers of topographical surveying are planned in Kazakhstan, in the regions of exploitation of very rich deposits of different useful minerals, and also for the planning and digging of canals to supply water to the expanding industrial regions of Karaganda, Sokolovo-Sarbaysk, and others.

The Seven-Year Plan of topographical and geodetic projects calls for surveys in the Central Asian republics. Surveys of the largest reserve of natural gas in the area, the Gazli, and also a whole series of cotton regions have been planned for Uzbekistan. A survey of regions adjoining the Kara-Kum Canal and a number of oil-bearing regions on the eastern shores of the Caspian Sea has been planned for Turkmenia. A survey of agriculture regions and regions where prospecting is going on for useful minerals has been planned for the Kirgiz and Tadzhik Republics.

Topographical survey projects will be fulfilled:

1) In mining and prospecting regions for the Ministry of Geology and Protection of the Underground Resources of the USSR.

2) In the most important estuary floodlands and irrigated regions of the Kazakh SSR.

3) In the regions of the lower reaches of the Shilka and Argun rivers, also in the upper reaches of the Amur River.

4) In cities and populated points in Moscow Oblast in connection with plans for supplying them with gas.

5) In the ore areas of the Kursk Magnetic Anomaly and for the Belgorod and Kursk National Economic Councils.

6) In the region of the water reservoir for the Vilyuy Hydroelectric Power Station.

In addition to topographical and geodetic projects connected with orders from different organizations, the Seven-Year Plan calls for systematic up-dating of topographical maps for individual regions of the USSR.

In connection with the large increase in the amount of topographical and geodetic work to be done in the eastern and northern regions of the USSR, plans have been made to transfer topographical and geodetic subdivisions from southern, central, and western regions in the 1959-1965 period, which will require capital investments in construction of housing and production facilities.

The transfer of topographical surveys to the east and the north has given rise to the problem of extending accurate coordinates and altitudes to these regions to form a single state system. As is well known, topographical maps of regions of difficult access, on the scale of 1:100,000 are based on astronomic points in many cases. Now it will be necessary to set up accurate geodetic nets, in the first instance, an astrogeodetic net of Class 1 in order to justify the large-scale maps of these regions. These and many other reasons have made the need for completing the astrogeodetic net of the USSR on accelerated schedules an urgent need. In spite of the exceedingly complicated physical geographical conditions prevailing in the regions to be included in these projects, the plans call for the essential completion of the astrogeodetic net of the USSR in this Seven-Year Plan.

New Technology

Fulfillment of the great and complex tasks which stand before the Topographical and Geodetic Service will be impossible without the introduction and the production of new, more rational methods of work, highly productive devices and instruments, and without the automatization and mechanization of production processes.

A special role has been assigned to the use of optical and radio range finders in geodetic work which will permit a great change in the technology of constructing geodetic networks and considerable savings in

monetary costs. Our Central Asian enterprise has already made successful use of a high-precision optical range finder in measuring bases for a period of 2 years. The need for constructing base nets dropped, the process of making measurements became far more productive, and the difficulties connected with selecting bases declined. There are prospects of the possibility of replacing triangulation strips and nets with polygonometric traverses and nets produced with optical and radio range finders.

The transition to the construction of triangular wooden towers means a considerable economy in effort and monetary outlays. The wider use of metal portable towers will also permit construction of large triangulation nets with smaller outlays.

The use of two-scale aerial photography is expected to have a significant effect. Devices for office processing of the results obtained from aerial photography have been given a large place in the plan for the development and introduction of new equipment. The Drobyshev stereograph is being improved (the production of two new models, the SD-1M and the SD-2 is planned). The universal stereometer is under improvement. The production of three new models of the Drobyshev stereometer, the STD-3, STD-4, and the STD-5, is being planned. A photoreducer of new design, a rectifier for photographs of mountainous regions, and a field stereometer for determining elements of relative orientation (PS-1) are under development. Devices for determining elements of absolute orientation of aerial photographs are being improved.

The development of aerial cameras with larger picture sizes is being planned. The use of the Romanovskiy stereo projector is being extended. New wide-angle objectives with higher resolving capacity are being designed. Radiogeodetic stations designed for control of topographical maps on a scale of 1:25,000 are being improved. The introduction of electronic machines for making compensating computations has been started.

In order to rationalize the principal geodetic and astronomical work, a new high-precision optical theodolite is being put into production; a passage instrument with a meniscus tube and photographic registration, a prism equiangulator, a zenith telescope, and quartz field chronometers are being developed; also, automatic chronographs and micrometers are being put into production on a wide scale. The introduction of new automatic alidades, surveying instruments with self-aligning axis of sight and with inclined beam, and optical range finders is expanding. Radio communications with all field subunits are planned.

In order to mechanize laborious processes it is planned to make extensive use of gasoline power saws, tractors, truck cranes, truck-mounted hole diggers, and excavators for construction and logging work; it is also planned to supply subdivisions with automotive equipment capable of operating on rough terrain and with air transportation.

Instrumentation

The draft of the prospective plan for 1959-1965 for the aerogeodetic Enterprise stipulates:

	In 1965 (in percent of 1958 level)
Gross production	132.6
Gross production in natural units	
OT-02 optical theodolites	155.6
TT-2/6 and TVO triangulation theodolites	100.0
Topographical stereometers	78.3
High-precision stereometers	150.0
Drobyshev stereographs	173.0
Base-line devices	78.1
Aerial cameras	133.3
Hydrostabilizer apparatus	180.0
Radar altimeters	180.0
Lens stereoscopes	150.0

In addition, plans have been made for the production of 55 high-precision optical range finders and 20 high-precision radio range finders by 1965.

The geodetic and stereophotogrammetrical devices and instruments produced are to be used to equip topographical and geodetic projects of the Main Administration of Geodesy and Cartography and to satisfy the needs of other branches of the national economy.

It is necessary to note that the capacity of the instrument manufacturing enterprises of the GUGK is not sufficient to satisfy the needs of the national economy; and in this connection, the GUGK has raised the question before higher agencies of the construction of a new plant for manufacturing photogrammetric instruments with a program of 25-30 million rubles. This question received a favorable response.

The Cartographical Industry

The volume of production in the cartographical industry in 1959-1965 is to be on the following levels

	In 1965 (in percent of 1958 level)
Gross production	166.5
Production of topographical maps	135.3
Production of educational maps	176.2
Production of educational atlases	150.0

Production of political and administrative maps	107.1
Production of contour training maps	173.9
Production of standard atlases for geography textbooks	2,287.0

The prospective plan for 1959-1965 calls for increasing the output of educational maps on cloth in 1965 by 85 percent over the 1958 level; this growth will be spaced evenly over the years.

The following large cartographical works are to be published in 1959-1965: an agricultural atlas of the USSR, an over-all atlas of the USSR, an over-all atlas of the Chinese People's Republic, a physical geographical atlas of the world, a new edition of the Soviet Atlas of the World, also atlases of the republics, krays, and oblasts.

In order to fulfill the projects outlined in the prospective plan for 1959-1965, it will be necessary to build a new cartographical factory (in Kiev) and to reconstruct the Tbilisi and Tashkent factories. Moreover, it will be essential to replace obsolete machinery in all the map factories with new, more productive off-set printing machinery in 1959-1965.

Personnel

In order to fulfill the Seven-Year Plan for topographical and geodetic work, the Main Administration of Geodesy and Cartography will need 3,118 engineers and 7,349 technicians. The engineers will be trained in geodetic higher educational institutes and the technicians in the eight existing technikums [technical secondary schools]. Specialist cadres must be trained in such a manner that they will be capable of carrying out complicated tasks under the very difficult physical and geographical conditions which are characteristic of the regions in which they will work.

The XXI Congress and the June Plenum of the Central Committee of the Communist Party of the Soviet Union have set great tasks for the Soviet people in order to achieve the further mighty development of the national economy. Soviet geodesists, topographers, and cartographers will direct all their efforts to construct geodetic nets and to satisfy the needs of all branches of the national economy of our socialist Motherland in respect to topographical and geographical maps.

III. FUTURE DEVELOPMENT OF THE PLANS AND PROGRAMS FOR THE CONSTRUCTION OF THE STATE GEODETIC NETWORK OF THE USSR

Pages 17-38

S. G. Sudakov, Deputy Chief
of the Main Administration
of Geodesy and Cartography,
Ministry of the Interior
USSR

The establishment of a state geodetic network, along with topographical and cartographical activities, is the chief task of the Geodetic Service of the USSR. Soviet geodesists have always ascribed particular importance to problems connected with the planning of the construction of geodetic nets. They have been obliged to do this, not only because of the continually growing role of geodetic nets in the topographical mapping of the country on a large scale, but also because of the necessity for solving the many scientific and technical and engineering problems which arose in the course of socialist construction. The requirements of the national economy and the defense of the nation in respect to topographical maps and a geodetic network have brought about a rapid tempo in the development of geodetic nets and the necessity for their systematic improvement.

Plans have been made to conduct projects at the same fast tempo in the forthcoming Seven-Year Plan. The Seven-Year Plan for the GUGK calls for determining 1.8 times as many points for the state geodetic network as were determined in 1952-1958, which will permit a radical change in the geodetic coverage of the territory of the nation by the end of the Seven-Year Plan. At the same time, the plan calls for further increases in labor productivity, reduction in labor costs, and improvement of the quality of geodetic nets.

Before passing on to a discussion of the individual problems for the further development and improvement of the plans and programs for the construction of state geodetic nets, we shall give a brief description of their present status and the possibilities which must be taken into account in the forthcoming projects.

The Astrogeodetic Network of the USSR

The foundation for the development of the modern astrogeodetic network of the USSR was laid by the work of the Corps of Military Topographers in 1910. This very important event was preceded by a critical analysis of first-order triangulation in a commission of the Corps of Military Topographers consisting of the most important geodesists of that time: V. V. Vitkovskiy, N. Ya. Tsinger, I. I. Pomerantsev, N. O. Shchetkin, K. V. Sheringorst, N. D. Artamonov, F. D. Vitram, and others. The commission recognized that the first-order triangulation established in the 19th century did not meet the requirements of proper definition

of geodetic and topographical work and that measures should be taken to construct a new first-order triangulation on more modern principles. After a lengthy discussion in 1907 and in 1910, the commission recommended that new projects be carried out to develop first-order triangulation in a systematic manner independent of the old projects, by constructing strips along meridians and parallels about 300 versts apart. Bases should be measured at junction points and astronomical latitudes, longitudes, and azimuths should be determined.

Work on the Pulkovo-Nikolayev strip was started on these principles. These same propositions were adopted by the Military Topographical Administration and the Higher Geodetic Administration for projects conducted during 1923-1928.

In 1928 F. N. Krasovskiy suggested a new plan and program for first-order triangulation in which he proved convincingly that the polygons should be decreased to 800 kilometers and the links (with bases and Laplace points at the ends) to 200 kilometers. F. N. Krasovskiy's plan had the purpose of increasing the accuracy of first-order triangulation and to improve the conditions for developing and adjusting lower-order triangulation. The plan and program established by F. N. Krasovskiy were adopted by the principal geodetic establishments and did not undergo any significant changes for 30 years.

From the very outset, the USSR developed first-order triangulation as an astrogeodetic network which permitted solving not only the practical but also the scientific problems of higher geodesy. The presence of dual Laplace points at the vertices of the polygons made it possible to construct links of chains of simple triangles, that is, the most economical form, a factor of great importance for the USSR.

The data presented indicate that the astrogeodetic net of the USSR is still far from completion. In the northern and eastern regions it is represented either by strips of great length or by enormous polygons; in a number of other regions it is represented by polygons which are smaller but still far from the normal size.

The construction of an astrogeodetic net was somewhat retarded in recent years due to the diversion of personnel to work on the development of second- and third-order triangulation, but measures were taken in 1958 to intensify work in order to complete construction of this astrogeodetic net over the entire nation in the next 7 years. Astro-gravimetric levelling should be fulfilled in both the European and Asiatic parts of the USSR in this period.

The enormous amount of material which will be collected as a result of these projects and the new adjustment of the astrogeodetic net will make it possible to solve a number of very important problems of scientific and practical significance.

In spite of the fact that the astrogeodetic network of the USSR was constructed over the course of many decades, it is a homogeneous structure and, with some rare exceptions, a structure of high reliability. One can judge this by errors made in measuring angles, and also by errors of closure of azimuths and bases in the links of the astrogeodetic net. The pertinent data are presented in Table 1.

TABLE 1

Year of Execution of Project	Average Number of Points in Link	Average Length of Links in Kilometers	Average Error in Measured Angles, Computed from Closure Errors in Triangles	Average Error of Closure of Bases (In Sixth Place of Logarithm)	Average Error of Closure of Azimuths
Before 1917	19	281	± 0".66	± 5.8	± 2".49
1918-1929	17	219	0.68	6.3	1.56
1930-1934	17	204	0.71	7.3	1.64
1935-1939	17	189	0.61	5.6	1.41
1940-1945	17	205	0.60	6.2	1.85
1946-1950	18	208	0.57	7.8	3.08
1951-1955	18	172	0.49	4.3	1.98
Average	18	210	0.60	6.2	2".00

The base and azimuthal closing errors along all links, with the exception of six, are in good agreement with the figures given above, which are determined on the condition that angles have a mean square error of ± 0".7; the final sides of the base nets 1:350,000; and the dual Laplace azimuths ± 1".0 [see following Note].

[Note:] A. M. Starostin stated in his article "An Investigation of the Accuracy of Determination of Laplace Azimuths" that adjusted Laplace azimuths have an error on the order of 1, 4--1".8. If we accept his conclusions, then we should have to explain the azimuthal closing errors in the links as errors in the Laplace azimuths, not as errors of triangulation angles. In analyzing azimuthal closing errors, it is essential to bear in mind that measured triangulation angles contain, in addition to random errors, a small systematic error with a minus sign caused by irregular use of a test telescope in measuring angles. The predominance of negative closing errors in triangles in eastern and northern links is probably explained by this.)

In spite of the fact that the astrogeodetic net of the USSR has not been completed yet, it has permitted two very important measures to be carried out: obtaining the dimensions of the F. N. Krasovskiy reference ellipsoid which is accepted in the USSR and other socialist countries, and introducing a single system of geodetic coordinates in many regions of the country.

The construction of the astrogeodetic network is the result of the efforts of two geodetic agencies - the Main Administration of Geodesy and Cartography [see Note below] and the Military Topographical Administration. Such a concentration of first-order projects created favorable conditions for achieving high accuracy in geodetic measurements.

([Note:] In the past: the Higher Geodetic Administration, the Main Geodetic Committee, the Main Geodetic Administration, the Main Hydrogeological and Geodetic Administration, and the Main Administration of State Maps and Cartography.)

Second-, Third-, and Fourth-Order Triangulation

One can divide the development of second-, third-, and fourth-order triangulation into three periods which are distinguished from each other by their special features.

The first period (1918-1936). During this period the principal geodetic establishments of the nation did not have the personnel and funds for developing lower-order triangulation. At the same time, especially from 1929 to 1935, a great need arose for geodetic nets to serve as a basis for topographical maps for agriculture, also to meet the needs of other national economic measures put into effect to implement the plans of the first five-year plans. Under these circumstances, departmental geodetic projects and, in particular, the projects of land exploitation agencies acquired a great development.

The almost complete lack of precision instruments for measuring angles compelled geodetic organizations to use theodolites of low accuracy. As a consequence, low-order triangulation, third-, fourth-, and even fifth-order triangulation, became highly developed.

The development of second-, third-, and fourth-order triangulation up to 1937 can be shown by the data of Table 2.

TABLE 2

Years	Orders of Triangulation 2	3	4	5	Total
Up to 1929	1852	3823	1625	1557	8,907
1929-1937	9249	45126	20975	31228	106,578
Total	11101	48949	22650	32785	115,485

	Which Includes GGU	Narkomzem	Others
Up to 1929	2280	4225	2372
1929-1937	30643	54257	21678
Total	32923	58512	24050

The predominant development of triangulation of lower orders gave rise to all sorts of simplifications in geodetic measurements. The plan for developing "filling-in" triangulations worked out by F. N. Krasovskiy, even though adopted, was applied almost not at all in practice. Moreover, at the insistence of agencies of the Narkomzem [Narodnyy Kommissariat Zemledelya -- People's Commissariat of Agriculture], the Gosplan of the USSR approved supplements to instructions to the GGU [Glavnoye Geodezicheskoye Upravleniye -- Main Geodetic Administration] in respect to second-order triangulation in 1930 and instructions in respect to third-order triangulation in 1930. These instructions actually excluded in practice the development of the orders of triangulation specified by F. N. Krasovskiy's plan.

The lack of a firm plan for constructing second- to fourth-order triangulation, the lack of coordination in work methods, and unsatisfactory marking of points led to a situation in which the enormous networks established prior to 1937 rapidly lost their significance. In this connection, it is necessary to note that the Geodetic Committee of the Gosplan which had existed at that time and the subsequent Interdepartmental Geodetic Council did almost nothing to bring the necessary order into geodetic projects.

The second period (1938-1947). During this period the construction of "filling-in" triangulation was changed for the better, as compared with the preceding period. The well-known decree of the government of 15 June 1935 played a decisive role in the cause of normalizing and improving geodetic work. It was pointed out in this decree that "the lack of an agency responsible to the government for mapping the USSR, the scattering of surveying and cartographical projects among many departments and organizations, and the lack of a single plan of surveying and cartographical projects do not correspond to the interests of the state and do not meet the requirements of the national economy."

This decree established the Main Administration of State Surveying and Cartography which was made responsible not only for the development of state geodetic nets, but also for supervision over the work of departmental organizations.

Normalization of geodetic projects began from the time that the new agency started to distribute large appropriations from the state budget for the development of geodetic nets, topographical surveys, and the compilation of maps, and also for construction and equipment. This made it possible to expand the construction of state geodetic nets in a short time, thus markedly decreasing the work of departmental organizations which were inadequately prepared for such work. The departmental geodetic projects which remained on a comparatively small level at this time were improved by the measures put into effect by the state geodetic supervisory agencies. In 1937 the GUGSK [Glavnoye Upravleniye Gosudarstvennoy S"yemki i Kartograffii - Main Administration of State Surveying and Cartography] put the instruction into force on the construction of second- to fourth-order triangulation which almost wholly restored F. N. Krasovskiy's plan; it was also adopted as the basis during the development of the Fundamental Propositions of 1939. All this played a significant role in the cause of improving the geodetic networks.

This period was marked by the development of dense second-order nets which were constructed to serve as a basis for topographical maps on scales of 1:25,000, 1:50,000, and 1:100,000.

The quantitative results in second- to fourth-order networks were smaller than those achieved in the preceding period, as most of the personnel of the geodetic establishments were busy fulfilling military missions during World War II.

The plan for construction of state geodetic networks adopted in 1939 possessed important shortcomings in spite of its apparent orderliness, and these shortcomings became more and more obvious with the passage of time. Its principal shortcoming was the fact that the objective and the accuracy of the state geodetic network were defined only by the requirements of the geodetic basis for topographical maps on a scale of 1:10,000, that is, the requirements of comparatively small-scale maps. Such a restriction of the service role of the state geodetic network led to the necessity of constructing departmental nets

to serve as a basis of topographical maps on larger scales and to solve various types of engineering problems. For this reason, large geodetic nets were established in all industrial regions which were not connected among themselves nor with the general state network.

The accuracy of measurements in state nets specified in the Fundamental Propositions of 1939 turned out, after some time, to be in conflict with the possibilities which came to light in geodetic field work, in connection with improved instruments for making angular and linear measurements. Without any justification at all, a low accuracy of angular measurements and a primitive plan for network construction were specified for third- and fourth-order triangulations. A disdainful view of minor networks as something incomplete and temporary was expressed also in a simplified design of centers for stabilizing points in the localities.

The third period. A large portion of the shortcomings which were present in the construction of geodetic nets were eliminated in 1948. The draft of the new fundamental propositions which was worked out, then the Fundamental Propositions of 1954, laid the foundation for establishing state geodetic nets of high accuracy which would make it possible to solve an incomparably wider circle of geodetic problems.

The different features of the new second-, third-, and fourth-order nets which distinguish them from the nets constructed according to the Fundamental Propositions of 1939 are as follows:

1) Primary second-order strips are missing;

2) An increase in the accuracy of angular measurements: in second-order nets - down to 1" [of arc]; third order - down to 1".5; and fourth order - down to 2".

3) Improved construction of fourth-order triangulation;

4) Regulation of the degree of development of networks to correspond to the scales of topographical maps;

5) The sequence of development of networks of different orders was established.

6) The obligatory definition of orientation points for tying-in detailed geodetic nets;

7) The stabilization of points in the field by centers was markedly improved.

The introduction of the new plan and program into practice made it possible to strengthen the position of the state geodetic nets and to carry out the unification essential and useful in geodetic work. At present, almost all departmental organizations are doing triangulation work in accordance with the Fundamental Propositions of 1954.

The actual accuracy of angular measurements in second-order nets is characterized by an error of $\pm$ 0".75 and in third-order nets - $\pm$ 1".0; only in individual instances have these errors reached $\pm$ 0".69 and $\pm$ 1".3 respectively.

Beginning in 1948, second- and third-order geodetic networks have been constructed to serve as the bases for topographical maps on scales of 1:25,000 and 1:10,000, and this has determined their intensified development in many regions of the country. The networks which have been constructed occupy an area of many millions of square kilometers. This area will be almost twice as large when the plan of the geodetic seven-year period is fulfilled.

There are grounds for assuming that during this period very large-scale surveys and the corresponding geodetic nets will also undergo marked development. One may judge this by the data of Table 3, which presents the volume of topographical and geodetic projects fulfilled by departmental organizations in 1957 and 1958.

In addition, it is necessary to take into account that the Main Administration of Geodesy and Cartography began to fulfill surveys on a large scale and to construct fourth-order nets in 1958.

TABLE 3

Types of Project	Unit of Measurement	Fulfilled, in percent In 1957	In 1958
Second-order triangulation	Points	100	127.9
Third-order triangulation	Points	100	123.3
Fourth-order triangulation	Points	100	102.9
Total		100	111.2
Polygonometry with an accuracy of 1:25,000	Km	100	157.3
Other types of polygonometry	Km	100	110.8
Total		100	122.0
Topographical surveys			
On a scale of 1:2,000 and larger	Km^2	100	107.3
On a scale of 1:5,000	Km^2	100	134.1
Total		100	125.2

The Purpose of the Astrogeodetic Network

When the astrogeodetic network has been constructed over the entire territory of the nation and adjusted properly, it will provide data of enormous value for the solution of the scientific problems of higher geodesy. This assertion is undisputable and obvious. Its role in the construction of the state geodetic nets has become something materially different. As soon as the accuracy of all orders of triangulations has been increased several times, the astrogeodetic network will not be regarded as the chief basis for all subsequent geodetic constructions. One may be convinced of this upon comparing the figures which describe the accuracy of a series of first-order triangulations with contemporary second-order triangulations. (Computational errors refer to nets of equilateral triangles; errors in initial data are neglected.)

	First-Order Strips	Second-Order Nets
Error in sides	1:162,000	1:410,000
Error in direction angle	± 1".3	± 1".0
Error in position of most remote point	± 1.00 meters	± 0.35 meters

As may be seen here, second-order triangulation is more accurate even though it is a subsequent construction.

This constitutes the contradiction and the singularity of the state geodetic net of the USSR. Generally speaking, it would be possible to reject the construction of such an astrogeodetic network and construct in its place a highly accurate, dense net which would make it possible to solve scientific problems and which would serve as an adequate basis for constructing state geodetic nets. In this case, however, the construction of a highly accurate astrogeodetic network would take an enormous amount of time during which special systems of coordinates would be established in many regions of the country, a situation that could not be tolerated, due not only to cartographical but also to many other very important considerations. In order rapidly to cover all areas of the USSR under a single system of geodetic coordinates, it will be necessary to make use of a polygon-type astrogeodetic net as the most suitable and the most accessible construction.

Second-order triangulation has no need for the initial long sides of first-order triangulation, since the basis on which it (second-order triangulation) is constructed is derived from the far greater accuracy of its sides. The same thing can be said of its orientation, as it has Laplace azimuths.

Thus the use of an astrogeodetic net is required only to ensure the unity of a system of coordinates in second-order triangulation. This problem can be solved if points at the vertices of the polygons of the astrogeodetic net and those of its ordinary points which are selected as a result of study of the deformations of the polygons are defined as initial (firm) points when adjusting second-order networks. Such a selection of initial points will permit avoiding significant distortions in second-order nets tied in with a single coordinate system.

(The reverses which have occurred in adjusting second-order nets are explained chiefly by incorrect selection of initial data. In particular, firm points of an astrogeodetic net located close to each other but still belonging to different systems have always caused large corrections in measured elements. The same thing occurs when second-order nets are adjusted in part in polygons with free vertices or in polygons which are not compatible for joint adjustment. In polygons of normal dimensions adjusted in 1942-1945, the errors in the adjusted angles of second-order triangulation rarely exceeded $\pm 1''.3$.)

This procedure for developing geodetic networks must be applied until the construction and adjustment of a highly accurate dense network over the entire nation or over large parts of it have been completed. [see Note below]. This obviously cannot occur in less than 15-20 years. Up to this time, the status of geodetic nets adjusted in polygons of the astrogeodetic network must be considered temporary, but adequate for solving many problems.

([Note:] It is obvious that when adjusting a dense network, it will be necessary to make use, in a suitable form, of a transition to the lengths and azimuths of geodetic lines calculated according to elements of the dense net in order to form a system of large triangles or firmer figures. In routine adjustment of a polygonal astrogeodetic net, it will be necessary to make use of this method in all polygons in which second-order triangulation has been completed. In this instance the links in first-order triangulation will have to be tied in with second-order nets.)

The ratio of accuracy of elements of first- and second-order triangulations provides grounds for refusing to tie second-order nets to sides of first-order nets, and for having them coincide only at points. Such a procedure for control will make it possible to save significant sums on the construction of towers erected at first-order points.

On the Completion of Projects for the Construction of an Astrogeodetic Network for the USSR

After making a detailed study of the status and the possiblities of the scientific and practical applications of an astrogeodetic network for the USSR, the commission of the GUGK and the VTU adopted a resolution in 1957 concerning its further construction in accordance with

the Fundamental Propositions of 1954. The resolutions of the Commission approved by the GUGK and the VTU were published in the journal Geodeziya i kartografiya [Geodesy and Cartography] (No. 11, 1957). The only thing meriting special repetition is the fact that the Commission recognized that it would be inexpedient to make radical changes in the construction of the astrogeodetic net, since this would require large expenditures of money, labor, and time, both on the fulfillment of remaining work and the revision of a large portion of the work already fulfilled.

Moreover, in the interests of saving money, it was recognized as necessary to include part of the second-order control strips in the astrogeodetic network. After careful analysis, it turned out to be possible to make use of about 140 strips with a length of not less than 25,000 kilometers for this purpose. These strips are characterized by the following figures: average number of connecting triangles, 15; length, 167 kilometers; average error of measured angles (error of closure of the triangles), 0".92 (maximum of 1".2); average error of closure of bases, 11.1 units of the sixth place of the logarithm; and average error of closure of the azimuth, 3'.7. In order to include such strips in the astrogeodetic net, it was necessary to define additional base sides and dual Laplace points in them, after taking into consideration the special characteristics and quality of the measurements that had been made.

It is necessary to add to the foregoing that in a number of regions it is possible to replace strips of first-order triangulation with polygonometric links or with dense nets of first-order triangulation. The use of polygonometric links in which the lengths of the sides will be measured with optical range finders will provide significant economy in the construction of high towers and will not lower the reliability of the astrogeodetic net. Dense nets of first-order triangulation with sides averaging about 50 kilometers which can be constructed profitably in open mountainous regions will make it possible, without increasing outlays for the work, to obtain a net of higher quality in such regions, a net which can be made denser with notably smaller difficulties than in ordinary polygons, and with economy of funds on coordinating second-order nets with the astrogeodetic net. Carrying out this replacement of first-order strips should be regarded as an expedient and economically advantageous measure in the forthcoming astrogeodetic projects.

On the Construction of State Second-, Third-, and Fourth-Order Geodetic Networks

Modern achievements of science and technology, and also the generalization of work experience accumulated by the geodetic establishments, permit outlining a series of measures for the further improvement of second-, third-, and fourth-order state geodetic networks.

Geodesists should now take into account the appearance of new means of making linear measurements in the form of precision range finders which will permit measuring long distances with an error of 1:200,000 to 1:300,000. These instruments have a great advantage over the basic Jaderin instruments and can be used widely in the construction of state geodetic nets. The use of precision range finders will permit the elimination of the construction of base nets in triangulation and, in many cases, to pass on to constructing nets of the polygonometric type. Likewise, there is no doubt that the significance of electronic computers in geodetic work goes far beyond the bounds of the mere mechanization of computational work. By extending the possibility of mathematical processing of the results of geodetic measurements, computers are creating the prerequisites for introducing more highly perfected and economical forms of geodetic constructions into geodetic networks.

The introduction of precision range finders and electronic computers into geodetic field work will make it possible to increase productivity, reduce the cost of work, and markedly to raise the quality of state geodetic nets.

On the Density of the Points of the State Geodetic Net

The problem of the density of points in the state geodetic net required to serve as a basis for maps of various scales and for engineering projects is one of the most important problems in compiling programs. Improper definition of the density of points can give rise to various unfavorable consequences. An excessively high density would require enormous expenditures of money and time in the development of the state geodetic net even though it would be advantageous for subsequent topographical and geodetic projects. Insufficient density would not be advantageous, because there would always be great difficulties in the development of bases for maps and other detailed geodetic nets. In the first approximation, "normal" density should be density such that regular visibility suitable for geodetic measurements exists between adjacent points. (It is assumed here that the towers on the points are of sufficient height.) A distance somewhat less than 10 kilometers satisfies this condition if we neglect days of bad weather and days with fog and dense smoke. Such a distance should be considered a maximum in the development of geodetic nets if we take meteorological factors into account. (With distances between points of up to 10 kilometers, the curvature of the earth almost wholly covers the height of an instrument on a stand and the height of a simple pyramid or surveyor's rod.) However, in the final establishment of average distances between points, one must start with determining how well the initial network meets the necessary accuracy for nets of subsequent development. The wide use of analytic networks with polygonometry along with accurate range finders for the development of mapping nets and special-purpose

nets will permit some reduction in the density of the points of the state geodetic net while topographical maps are compiled according to standards established by present instructions.

Being guided by these considerations, one can adopt the following approximate standards for the density of points for maps of various scales.

For maps on a scale of 1:25,000 or 1:10,000, the distance between points of the state geodetic network should be, on the average, 7-9 kilometers, or approximately one point per 50-60 square kilometers. Such density of points is adequate for maps on a scale of 1:25,000 or 1:10,000, both for defining the planned coordinates of the points on the mapping net as well as for trigonometric levelling, which is widely used in field-edit surveying of aerial photographs. This same density can satisfy the needs of geologists at certain stages of geological prospecting and geophysical work and many other consumers.

The average distances between points of the state geodetic net when maps are to be made on a scale of 1:5000 should be limited to 5-6 kilometers, which will correspond to the standard of one point per 20-30 square kilometers.

When maps are to be made on a scale of 1:2000 and larger, the density of points of the state geodetic network must be established in accordance with the content and the accuracy of prospective topographical and geodetic projects. If the accuracy and degree of development of the mapping nets are needed not only for the compilation of plans on these scales, but also for the solution of complex engineering and technical problems, then the density of points of the state geodetical net should be brought to the standard of one point per 5-7 square kilometers. In all other cases the density can be reduced to one point per 10-15 square kilometers for such maps.

These standards of density define the limits of the development of the state geodetic networks corresponding to the requirements set for maps of a given scale. The density of points of the state geodetic network for maps on scales of 1:5000, 1:2000, and larger should also be reduced in order that the further development of geodetic bases should be better adapted to the solution of impending concrete tasks. The regulation of such nets should be worked out in detail on the basis of pertinent instructions and after taking into account the specific requirements of impending engineering and technical projects.

It is wholly understandable that such standards of density should not be extended to regions of impassable bogs, flooded river lowlands and sea coasts, or zones covered with perpetual snow. In such regions it is essential to plan a network of minimum density and to construct more detailed bases for maps, when necessary, with local conditions taken into account.

The planned reduction in the standard of density of points of the state geodetic network will make it possible to save large sums on geodetic projects.

The Procedure for the Development of State Geodetic Networks

As is well known, the state geodetic network is now being constructed with subdivisions into four orders: the first order - the astrogeodetic net; the second and third orders - to serve as bases for maps on scales of 1:25,000 and 1:10,000; and the fourth order - to serve as a base for maps on scales of 1:5000, 1:2000, and larger. It is not difficult to see that the accepted procedure for network development does not agree to the necessary extent with the stages of large-scale cartography. Second- and third- order networks constitute the chief geodetic bases for maps with scales of 1:25,000 and 1:10,000 while only fourth-order nets are used for developing the networks of points essential for maps on scales of 1:5,000 and 1:1,000. Such a procedure for developing networks creates definite difficulties in organizing geodetic projects, increases their costs somewhat, and repeated use of a network of the same order gives rise to great inconveniences in computing adjustments.

These shortcomings will not occur if there is just one definite order of the state geodetic network for each stage of cartography. Starting from this basis, it will be expedient to construct only second-order nets for maps on scales of 1:25,000 and 1:10,000; third-order nets for maps on a scale of 1:5,000; and fourth-order nets for maps on scales of 1:2,000 and larger. Then the following basic cases in the construction of state geodetic networks will be encountered in geodetic practice.

First case. When the scale of cartography is increased at different times from smaller to larger scales, from 1:25,000 to 1:2,000 and larger, the second-order net is densified progressively: a third-order net is used for maps on a scale of 1:5,000, then a fourth-order is constructed.

Second case. If mapping on a scale of 1:25,000 based on a second-order net is followed by mapping on a scale of 1:2,000 (and larger), the second-order net is densified only by a fourth-order net, skipping the third-order net.

Third case. Maps are made on a scale of 1:2,000 (and larger) before a second-order net has been constructed. In this case, only a fourth-order net is constructed for maps on scales of 1:2,000 and larger which will be included in the higher-order net when it is actually constructed.

Fourth order. Maps on scales of 1:2,000 or larger are to be made after a third-class net has been constructed for mapping on a scale of 1:5,000. In this case the third-order net is densified to a fourth-order net. When an adjacent region is to be mapped on a scale of 1:25,000 (or 1:10,000), the previously constructed third- and fourth-order nets will be included in the second-order net. (Inclusion of nets should be accomplished either by coincidence of points of the second order with those of the third or fourth order, or by calculating the necessary connections from third- or fourth-order nets.)

It is obvious that the second and the fourth cases will be encountered most frequently in mapping city areas. It should be noted that the existing practice of establishing a multi-order ruling geodetic basis in cities is not well founded and should be re-examined. Unfortunately, the rough draft of the instructions now being worked out by the Mosgorgeotrest again provides for the construction of multi-order networks.

With the proper accuracy of the lower-order nets, it seems to us that the procedure we have suggested here for developing state geodetic nets is more expedient than that which has been accepted up to the present time. (If, according to the accepted standard, five to seven points of a state geodetic net are required for mapping on a given scale, then such mapping can be done on the proper map basis.)

As is obvious here, the construction of state nets can be accomplished on the principle of "going from the general to the specific," which will be the ruling principle, as well as on the principle of "going from the specific to the general."

The construction of a second-order net with sides averaging 7-9 kilometers does change the accepted scheme for developing geodetic networks but does not involve any unfavorable consequences at all. With proper displacements of the base sides and Laplace points, the accuracy of the length of the sides and the direction angles in such a second-order net will not be lower than in second-order nets with longer sides. This conclusion is possible without complicated calculations. Reducing the length of the sides in a second-order net will mean only that angular and linear measurements will depend less upon atmospheric factors, recognition will be considerably simpler, and distribution of the points of a net will be more uniform. In this instance it will be possible to make some savings in the construction of towers, which can be judged on the basis of the data presented in Table 4, which were compiled from material taken from networks constructed in nine areas of different regions of the USSR. (The figures for Table 4 were taken from existing networks in order to avoid a subjective approach in evaluating expected savings.)

TABLE 4

Number of Section	Average Height of Towers of Second- and Third-Order Nets, in Meters	Average Height of Towers of Third-Order Nets Only, in Meters (Average Number of Directions 4)	Average Height of Towers of a Dense Second-Order Net with Length of Sides of 7-9 Meters	Difference of 4--2, in Meters
1	18.6	16.4	17.6	-1.0
2	15.1	14.2	13.7	-1.4
3	4.6	2.7	3.3	-1.3
4	28.6	26.1	27.2	-1.4
5	24.1	23.4	23.5	-0.6
6	30.1	28.4	29.4	-0.7
7	4.5	4.3	5.5	+1.0
8	23.5	22.6	23.6	+0.1
9	2.8	2.3	2.5	-0.3

Figures on the reduction in average heights of towers in second-order nets with sides of 7-9 kilometers are given in column 5 of Table 4. As may be seen here, the reduction in the height of the towers is markedly less than the reduction obtained by K. L. Provorov, but it is still significant and should not be neglected.

The transition to the construction of second-order nets with shorter sides should be regarded as a useful measure which will facilitate the execution of geodetic projects. Adjusting the net in a polygon consisting of 700-800 points should not cause special difficulties, since the methods worked out for calculating adjustments on electronic machines permit the adjustment of very large networks.

The Accuracy of Measurements in the State Geodetic Network

The experience gained in geodetic projects in the last 10 years proves that by using high-precision instruments of Soviet manufacture, Soviet geodesists are maintaining a higher level of accuracy in measurements in the state geodetic nets than that specified in the instructions. This proves that the principle laid down in developing the Fundamental

Propositions of 1954 -- "...to make geodetic measurements with the maximum accuracy attainable in mass projects" -- has turned out to be correct, as confirmed in the practical work of thousands of geodesists.

Large amounts of data on angular measurements collected over recent years make it possible to establish the following mean square errors in the instructions when measuring angles: in the astrogeodetic net about $\pm$ 0'.5, in second-order nets $\pm$ 0'.8, and in third- and fourth-order nets $\pm$ 1".0. The error in the length of the base sides in networks of all orders can be specified as no greater than 1:400,000, and that of ordinary sides in the networks as 1:200,000. These standards in the accuracy of angular and linear measurements must be accepted in future work in order that the large tolerances stated in the instructions may not hamper further improvement of the quality of geodetic networks. Priority must be given to revision of the tolerances for angular measurements in third- and fourth-order nets which were improperly established and which are so low that they are readily fulfilled even with gross violations of procedural rules and when work is done under unfavorable weather conditions.

In determining Laplace points, it is essential to adopt measures to increase the accuracy of astronomical azimuths to $\pm$ 1".0, thus ensuring an error in the dual Laplace azimuth on the order of $\pm$ 0".7 - $\pm$ 0."8.

High accuracy in measurements in state geodetic networks is also necessary in order to compensate for weak areas in the construction of nets which have to be tolerated on account of a number of serious considerations.

A Plan for the Construction of Second-, Third-, and Fourth-Order Networks

As is well known, the accuracy of the adjusted elements in a geodetic network depends to a great extent on the scheme of its construction. In order to establish a highly accurate geodetic network, it is essential to ensure not only high accuracy in making measurements, but also to make decisions in designing the scheme such that resulting geometric conditions can have a favorable influence on raising the accuracy of the length of the sides, the direction angles, and the coordinates of the points. This condition is satisfied by dense nets, a particular example of which is present-day second-order triangulation. The advantages of second-order triangulation are very important, which provides grounds for maintaining it in future projects.

Third- and fourth-order triangulations should be constructed in the form of dense nets, irrespective of whether they are independent or are included in a net of higher order. It is essential to make this remark, because the insertion of unified third- and fourth-order points is not always ensured by a firm connection of these points with higher-order points and, as a rule, does not provide for connections with adjacent points of the same order.

In our opinion, the condition of density of a net should be observed even when the state geodetic net is constructed in polygon form. In connection with the appearance of precision range finders, such construction should occupy a suitable place. As applied to nets of the polygonometric type, the condition of density should be formulated in the form of requiring that every determined point be tied in with the nearest neighboring points. This requirement usually requires the construction of nets in the form of rectangles in which all angles and sides should be measured.

In order to evaluate the relative merits of geodetic networks of different constructions, let us present the results of calculations made by the Central Computational Section of the GUGK under the guidance of D. A. Larin and A. A. Pchelina.

The mean square errors in the lengths of sides, direction angles, and the positions of points were computed for the nets shown in Figures 1, 2, 3, 4, 5, and 6. (The net shown in Figure 1 is goniometric; that shown in Figure 2 is anallactic (without measurement of angles); and those in Figures 3, 4, 5, and 6 are polygonometric.) The following assumptions were accepted in these calculations: length of the sides s = 12,500 meters, the error in the measured angle $m = \pm 0''.9$, the error in measuring length of the sides $\frac{m_s}{s} = 1:200,000$, and the error in the initial data equal to zero.

The results of the computations, as presented in Table 5, make it possible to draw some very important conclusions. (In actual nets the elementary figures differ considerably from the most advantageous forms, therefore the errors in elements of a net will be somewhat greater than those indicated in Table 5.)

TABLE 5

SUMMARY OF MEAN SQUARE ERRORS IN THE POSITIONS OF POINTS, LENGTHS OF SIDES, AND DIRECTION ANGLES

Number of Figures	Number of Points in Net	Mean Square Error in Position of Points (in Meters) No 1	No 2	No 3	No 4	No 5	No 6	No 7	No 8
Fig. 1	232	0.09	0.16	0.20	0.24	0.28	0.32	0.35	0.37
Fig. 2	232	0.16	0.23	0.33	0.42	0.51	0.62	0.70	0.58
Fig. 3	289	0.08	0.14	0.18	0.26	0.31	0.35	0.39	0.37
Fig. 4	289	0.10	0.14	0.19	0.26	0.30	0.35	0.40	-
Fig. 5	81	0.12	0.19	0.29	0.35	-	-	-	-
Fig. 6	81	0.16	0.28	0.37	0.44	-	-	-	-

	Mean Square Error of Lengths of Sides in Meters and of Direction Angles I	II	III	IV
Fig. 1	0.03 0".6	0.03 0".6	0.03 0".5	0.06 1".0
Fig. 2	0.05 1.2	0.05 1.2	0.05 1.1	0.05 1.5
Fig. 3	0.04 0.5	0.03 0.5	0.03 0.5	0.04 0.7
Fig. 4	0.04 0.6	0.04 0.5	0.04 0.5	-
Fig. 5	0.07 1.6	-	0.07 1.6	-
Fig. 6	0.11 1.9	0.15 2.2	0.11 1.9	-

Remarks: The errors in lengths and direction angles in networks shown in Figures 5 and 6 refer to the case in which corresponding points were not connected by direct measurements.

1. In the goniometric net (Figure 1) the errors of length of sides and the directional angles are practically identical in all parts of the net ($m_s = \pm$ 0.03 meters, $m_\alpha = \pm$ 0'.6) and grow approximately 1.5 times only on the edge. The error in the position of a point taken at maximum distance from the initial point (at Point No 7) $m_p = \pm$ 0.35 meters.

2. In the anallactic net (Figure 2) the errors of the lengths of sides turned out to be identical in all parts of the net (m_s = 0.05 meters), the error of the direction angles approximately twice that of the goniometric net ($m_\alpha = \pm$ 1".2), the error in the position of the most remote point (Point No. 7) twice that of the goniometric net ($m_p = \pm$ 0.7 meters).

3. In the polygonometric net of Figure 3, the errors of the lengths of the sides, the direction angles, and the coordinates of the points agreed almost wholly with the errors of the goniometric net ($m_s = \pm$ 0.03 meters, $m_\alpha = \pm$ 0'.5, and the position of the point $m_p = \pm$ 0.39 meters).

4. In the polygonometric net of Figure 4, the errors in the lengths and direction angles of the sides connecting the node points were equal to $m_s = \pm$ 0.04 meters and $m_\alpha = \pm$ 0'.7, respectively. The errors in the corrdinates of the node points were found to be almost the same as those in the net shown in Figure 3.

5. In the polygonometric nets of Figures 5 and 6, the errors in the distances and the direction angles between unconnected points were several times greater than those between points which were directly connected geodetically. In the net shown in Figure 5, $m_s = \pm$ 0.07 meters, m $= \pm$ 1".6; in the net shown in Figure 6 $m_s = \pm$ 0.11-0.15 meters, and $m_\alpha = \pm$ 1".9-$\pm$ 2".2. The errors in the position of the free vertices were almost twice those of the errors in the node points.

The general conclusion is that polygonometrical constructions with free vertices (that is, vertices which have only two ties each) are less accurate than goniometric, anallactic, and polygonometrical nets with vertices that are not free. The nets shown in Figures 1 and 3 had the highest accuracy.

Several works on the problem of the scheme for the construction of polygonometrical nets have appeared in the last 3 years which have expressed different viewpoints. In particular, one may point to the suggestions made by V. A. Velichko and I. I. Entin. (V. A. Velichko, "Geodesy and Aerial Photography," Izvestiya vysshikh uchebnykh zavedeniy, No. 2, 1957; I. I. Entin, Geodeziya i kartografiya, No. 6, 1959.) The basic shortcoming of the schemes suggested by V. A. Velichko and I. I. Entin (Figures 7, 8, and 9) is that they permit the construction of polygons in a net with a large number of free vertices. As a consequence, the inclusion of subsidiary points (third-order points) with polygonometric traverses or linear-angular intersections will be accompanied with a marked drop in the accuracy of the net. The same thing

will also take place with the inclusion of fourth-order points. According to approximate calculations, the nets shown in Figures 7, 8, and 9 will not have the required consistency in spite of the high accuracy of lengths and direction angles between points connected with geodetic measurements.

The calculations which have been made of the considerations stated here permit recommending the construction of a state geodetic net of the second order approximately like that shown in Figures 10 and 11, and nets of the third- and fourth-orders like those of Figures 12 and 13.

If we set up the condition that errors in the lengths of the sides and the direction angles in a dense goniometric second-order net should be approximately the same in all its parts, then to achieve this purpose it is essential that the bases be not more than 75 kilometers apart and that the Laplace azimuths be not more than 100 kilometers apart. (In independent third- and fourth-order nets, the bases should be located about every 20 triangles; Laplace azimuths are not required for these nets.) In a polygonometric net the Laplace azimuths should be the same distance apart as in a goniometric net. (The number of Laplace points in the state geodetic net has increased almost double, which makes it possible to conduct a more detailed study of the shape of the earth.)

It is not difficult to see that a normally developed state geodetic network will ensure a relative error close to 1:200,000 in the sides, that is, not greater than $\pm$ 2 centimeters with distances of 3-4 kilometers between points in a fourth-order net. With such an error in the original net and with a proper approach to the detailed control, one cannot only establish maps of any scale, including even those on a scale of 1:500, but even construct nets for solving many engineering and technical problems.

The construction of state geodetic nets in a polygonometric form is a new procedure which requires careful examination of many problems of theory and practice in order to avoid material errors from the very outset.

The new geodetic technology and new forms of geodetic constructions are making it possible to select in any region that method for constructing a geodetic net which will yield the best economic effect. In this connection, the planning of geodetic networks should include the clarification of technical and economic indexes essential for the final selection of the type of net as an obligatory stage.

* * *

Notes. The first note is in regard to the naming of orders of a geodetic net. It seems to us that second-order nets fulfill the role of first-order nets in form and fact, and thus should be called first-order nets. It is true that the facts remain unchanged, but the use of the previous name deprecates the role and the purpose of second-order nets. If the new name for second-order nets is accepted, then the

remaining nets will be called second- and third-order nets. In this case a first-order network could be called an astrogeodetic network.

The second note is in regard to the accuracy of geodetic nets. At times one hears discussions to the effect that geodesists strive in vain to construct highly accurate state geodetic nets, since their accuracy is now used in full in practice. It is difficult to agree with such viewpoints. If the distance between two points of the net is characterized by a mean square error on the order of 1:200,000, then one must admit at the same time that this error can reach 1:70,000 and even greater in some part. It is not difficult to see that such a net would scarcely ensure the normal inclusion of a polygonometrical traverse 4 kilometers long for which the relative error has been specified to be on the order of 1:25,000. Using modern means for making measurements and applying the most modern forms of construction of state networks, geodesists are, on the whole, approaching such qualitative standards which have been set as things which are not only not excessive but necessary. It is obvious that future practice will require further increases in the accuracy of state geodetic nets. Geodesists of the older generation know how the requirements have changed in respect to geodetic networks and it is difficult to imagine that these requirements will become less strict in the near future.

Under these circumstances it is impossible to refuse to make use of the achievements of geodetic science and technology for improving geodetic networks.

Of course, the foregoing considerations are of preliminary nature and they are subject, like many other suggestions, to careful study before work is started on the compilation of supplements to and changes in the Fundamental Propositions of 1954.

FIGURE APPENDIX

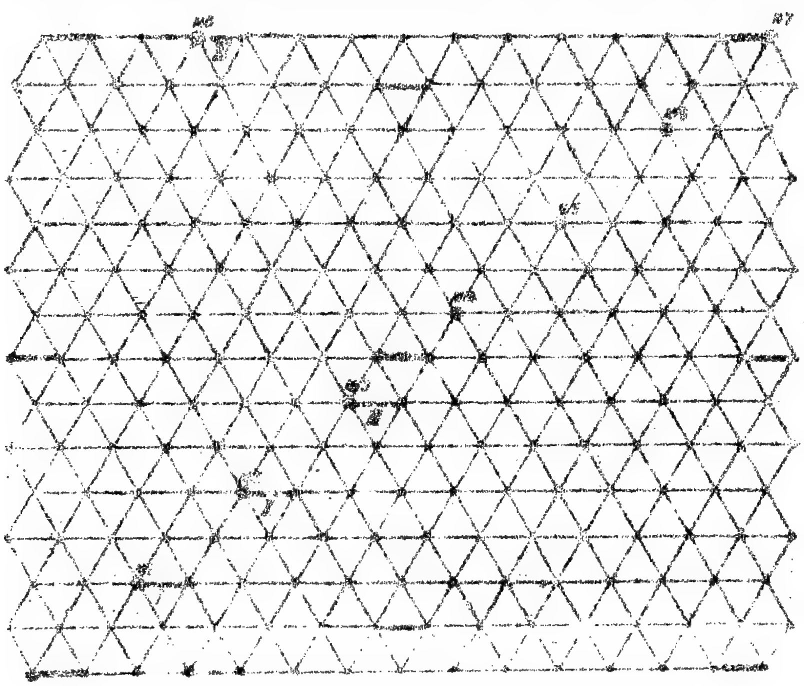

Figure 1

⊙ N4 Points for which the errors in coordinates have been calculated.

— — — Sides for which the errors in the lengths and direction angles have been calculated.

▲▲▲ Laplace azimuths

▬▬ Base sides

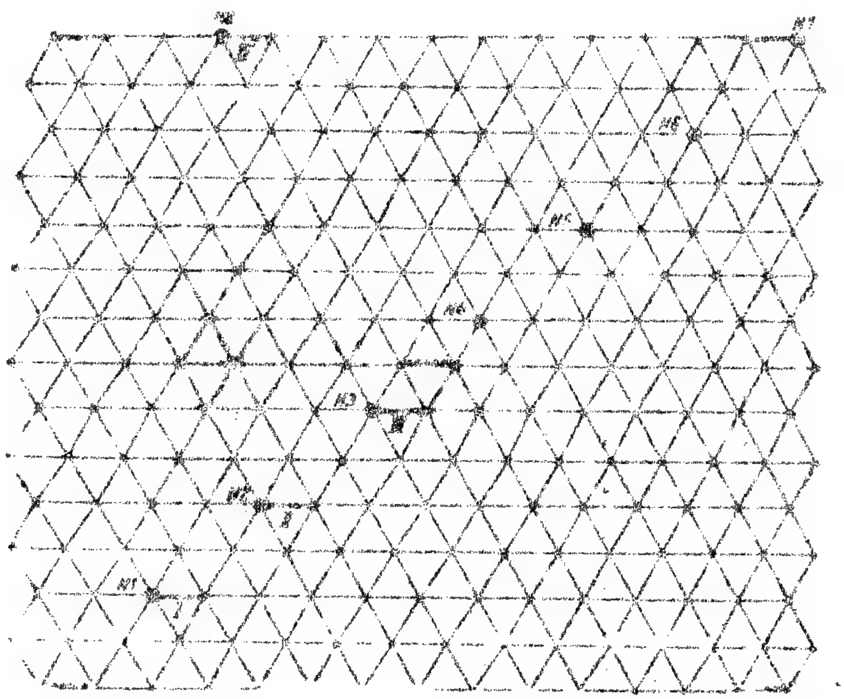

Figure 2. Symbols are the same as those of Figure 1.

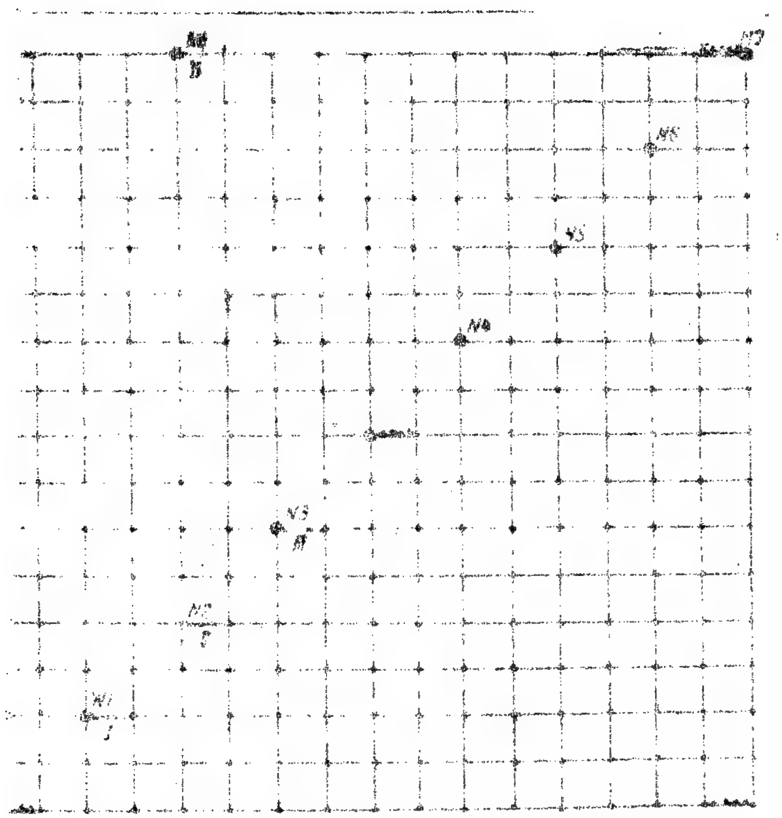

Figure 3

⊙ } Second-order points

Laplace azimuths

⊙ N2 Points for which the errors in coordinates have been calculated.

— — — - Places in which the errors in the distances between points and errors in the directions angles have been calculated.

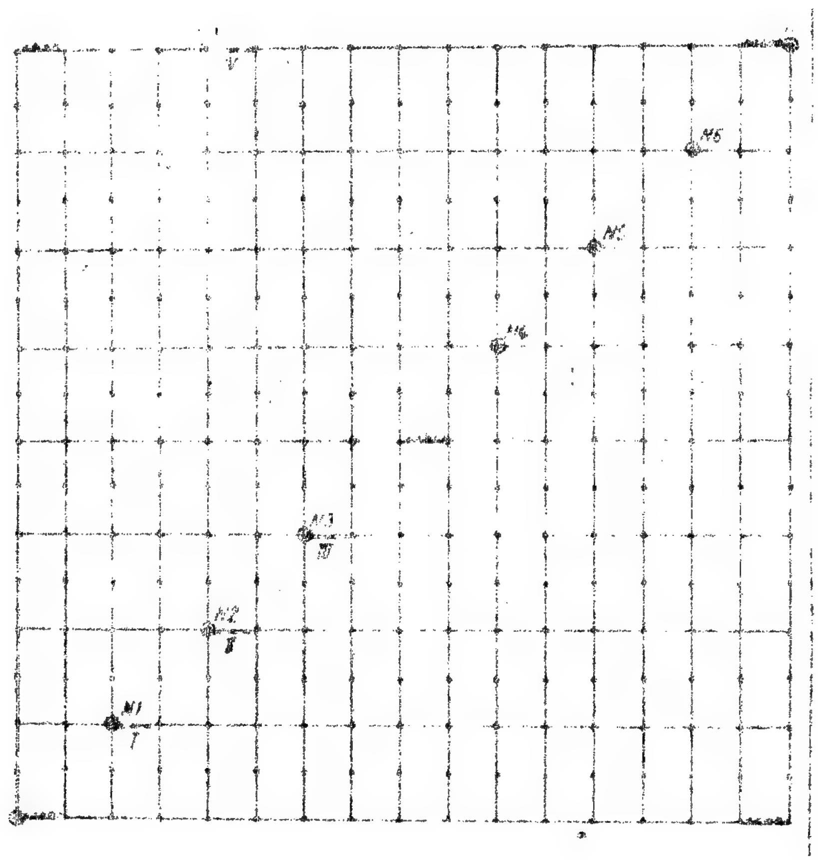

Figure 4. Symbols are the same as those of Figure 3.

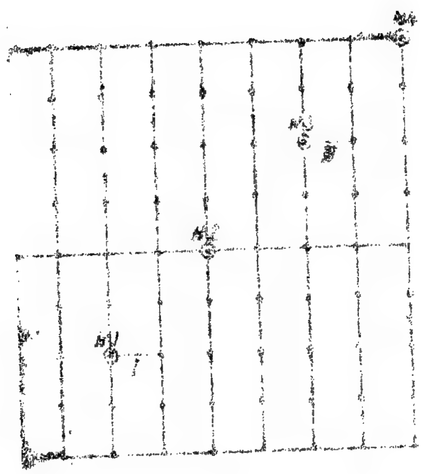

Figure 5

Node points of the second order

Ordinary points of the second order

Laplace azimuths

N2 Points for which errors in the coordinates have been calculated

Places in which the errors in distances between points and the errors in direction angles have been calculated

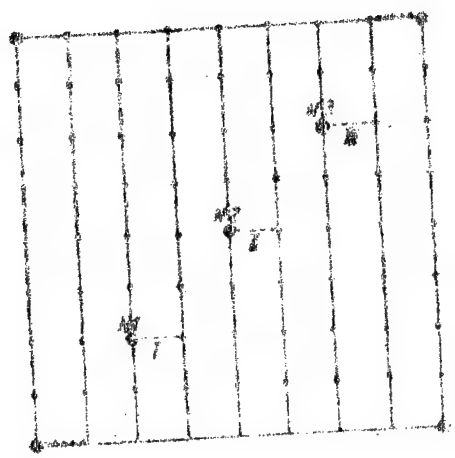

Figure 6. Symbols are the same as those of Figure 5.

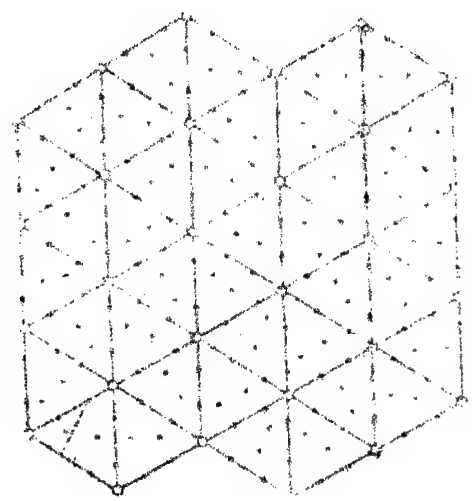

Figure 7

- Node points of the second order
- Ordinary points of the second order
- Points of the third order obtained from traverses or intersections.

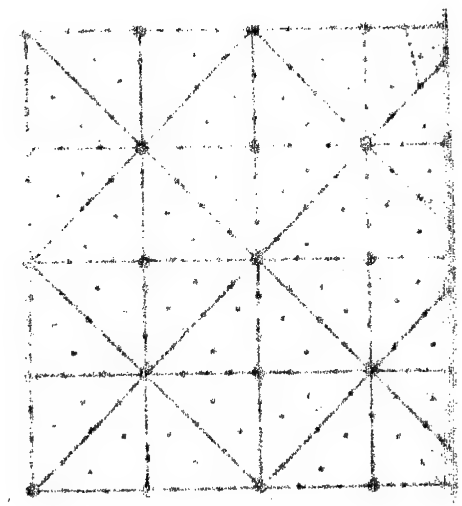

Figure 8. Symbols are the same as those of Figure 7.

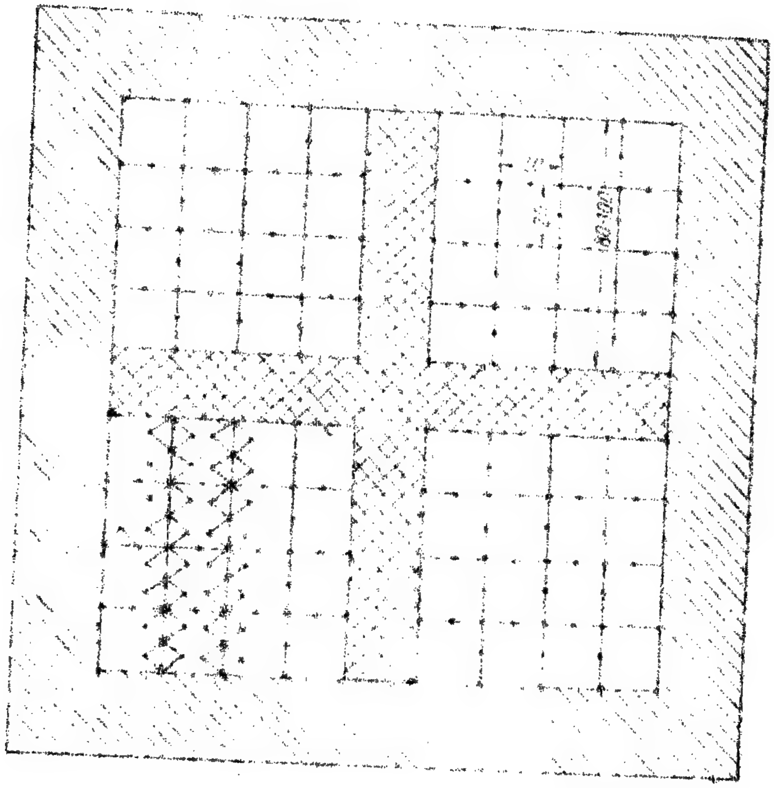

Figure 9

Strips of the first order

Base strips of the second order

Second-order points determined from polygometric traverses

Third-order points from intersections determined from second-order points.

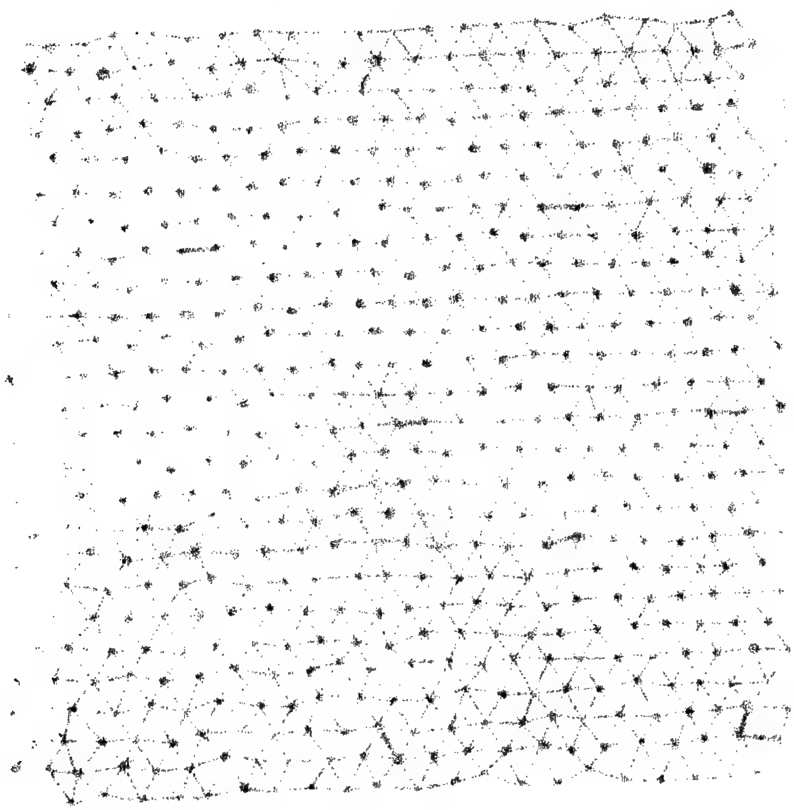

Figure 10

First-order points — Base sides

Second-order points — Laplace azimuths

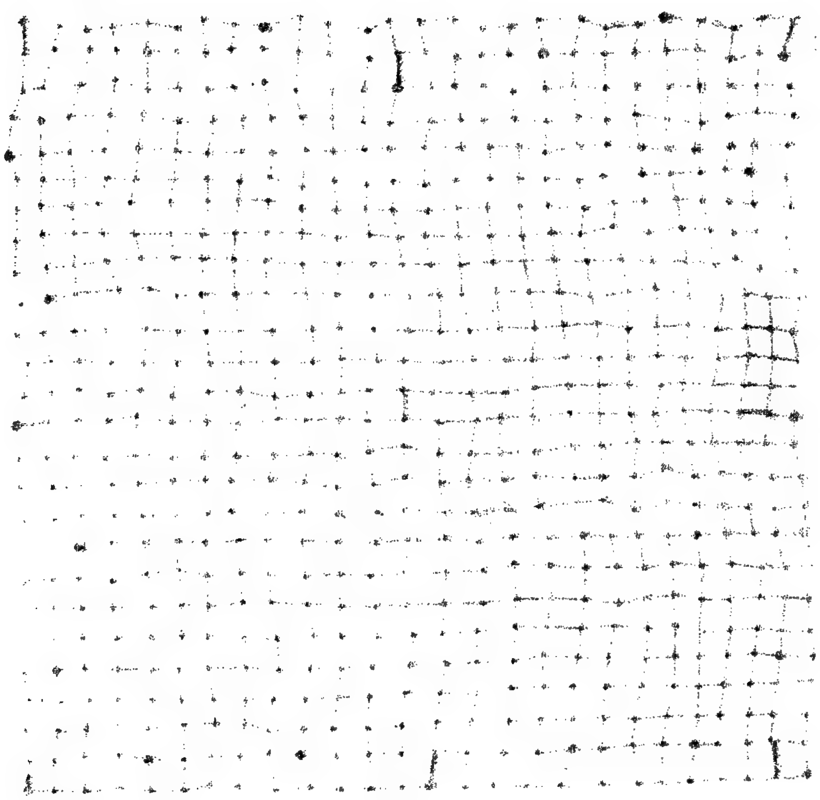

Figure 11

First-order points

Laplace azimuths

Second-order points

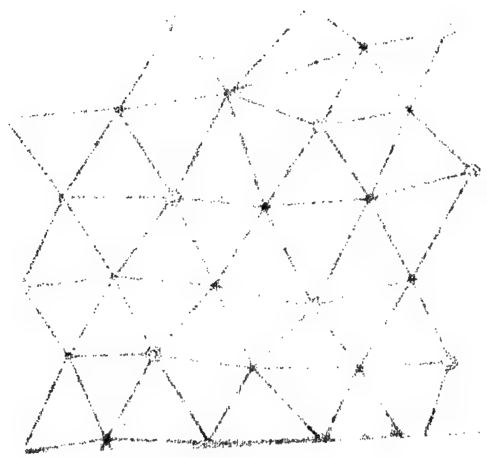

Figure 12

◎ Second-order points

• Third-order points

Remarks. In the development of a fourth-order net, the sign ◎ will be used to designate second- and third-order points.

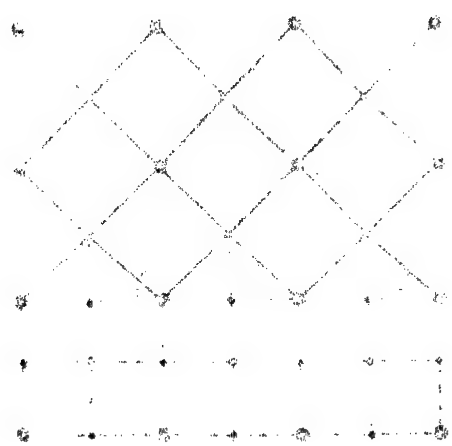

Figure 13

◎ Second-order points

o Third-order points

• Fourth-order points

IV. THE FUTURE PLAN AND PROGRAM FOR THE CONSTRUCTION OF THE STATE GEODETIC NETWORK OF THE USSR

Pages 39-56

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I. The Principles of the Construction of a State Geodetic Control Network

The construction of a control geodetic network is a matter of great importance to the state. Soviet geodesists have always devoted an enormous amount of attention to this problem, as they understand that in solving it the scientific and technological and the economic aspects of the matter must be taken into account in the most serious manner, and in accordance with the prospects for utilizing the geodetic network for science and production. Blunders in this matter involving losses of objectives and a single-minded purpose in solving this problem will lead to serious consequences which will be felt often in 10, 20, or more years. Subsequent repetition, substitutions, and rejection of previously completed projects are the result of blunders in the system of construction and definition of projects for establishing control geodetic networks.

There are not a few examples which confirm this conclusion in the practice of establishing control geodetic networks. For example, up to the 1880s, triangulation projects in our country, as is well known, were carried on in an unsystematic manner, by "provinces," without any general geodetic plan, and without the proper connections between individual triangulations. To the great chagrin of Soviet geodesists, the role and significance of these projects were lost completely and very rapidly.

The only model work of this time, the Struve Meridianal Arc, which was established in the first half of the 19th century, has not lost its scientific and procedural significance even to this day.

Bringing order into projects for establishing control geodetic networks and placing them on a definite program and plan was accomplished in our country after the Great October Socialist Revolution. From the moment that the Higher Geodetic Administration was organized in 1919, many problems of the development of geodetic field work came up anew. In the 1920s the VGU [Vysshee Geodezicheskoye Upravlaniye -- Higher Geodetic Administration] was given the assignment of developing systematic state topographical maps, and establishing first of all a geodetic base for these maps which would be simultaneously state and departmental. Only the establishment of a national geodetic basis

ensured national mapping in a systematic manner and of good quality, and at the same time, led to elimination of duplication and overlapping of projects.

The role and the contribution of F. N. Krasovskiy in working out plans and programs for state triangulation, linked with the profound ideas embedded in V. I. Lenin's decree, are generally known. Starting in 1928, the state control geodetic network began to be developed in accordance with a definite system and program, taking into account scientific and practical requirements and with a more or less reliable erection of signal stations calculated on lengthy service for the control network. From this time on, haphazardness in the construction of control geodetic networks was at an end in our country.

The following 20 years (1928-1948) proved that the system for constructing the state geodetic network did not remain unchanged, that it had its own dynamics of development, withal quite rapid. On the basis of an analysis of the problem as a whole and, in particular, an analysis of deformations in the control geodetic networks, Professor F. N. Krasovskiy developed the well-known system in 1928 for constructing a state geodetic network for the USSR. In the interests of bringing order into the development of networks of second, third, and lower orders within first-order polygons and acting on the basis of the above-mentioned analysis, F. N. Krasovskiy was compelled to require that first-order polygons be reduced down to dimensions of 200 x 200 kilometers (in place of the Pomerantsev polygons with dimensions of 400 x 400 kilometers).

Understanding how complicated and responsible the problems of establishing a state geodetic network are, F. N. Krasovskiy noted in his work of 1928: "I do not deny that still other schemes can be suggested for developing second-order triangulation" ([1], page 68). And in fact, life itself has suggested that changes be introduced in the scheme for constructing geodetic networks inside first-order polygons. As is well known, basic second-order networks did not become widespread. Almost from the outset, second-order triangulation was established in the form of base strips for filling in second-order networks. As a result, in connection with the development of the method of I. Yu. Pranis-Pranevich for adjusting the extensive geodetic networks by parts (in 1935-1936), the second-order base strips took on a merely auxiliary character. (according to the Fundamental Propositions of 1939) and lost their significance in the 1940s.

F. N. Krasovskiy's program of 1928 called for the construction of a state network of six stages: first-order strips, base strips of the basic nets and filler networks of the second order, third-order networks, and fourth-order density points (formed by intersections).

The Fundamental Propositions of 1939 called for the construction of a state network of five stages (without the basic second-order networks), and from 1940 four stages (without the basic second-order

networks). The filler second-order nets ($s = 10$-15 kilometers) had a mean square error $m = \pm 2''.0$-$2''.5$ in angular measurements.

The accuracy of construction of networks, according to the Krasovskiy program of 1928 and the Fundamental Propositions of 1939, was held approximately identical and was oriented to a map scale of 1:10,000.

In accordance with the suggestion made in 1948 by the Deputy Chief of the GUGK, S. G. Sudakov, a transition was made to constructing dense second-order nets inside first-order polygons ($s = 10$-15 kilometers) of higher accuracy with a mean square error in angular measurements $m = \pm 1''$ with bases located inside the polygon at every 70-100 kilometers; the second-order net was densified with third-order nets ($s = 7$ kilometers, $m = \pm 1''.5$) and fourth-order nets ($s = 4$ kilometers, $m = \pm 2''.0$.

The Fundamental Propositions of 1954 which legalized this transition, retained the four stages, the same principles of construction, and also the length of the sides in the densifying networks, but the accuracy of angular measurements in second-, third-, and fourth-order networks was raised materially.

Consequently, the accuracy of construction of the dense state networks was raised significantly.

The following circumstances had a favorable influence on the transition to the new system:

1) The achievements in methods and techniques of processing and adjusting extensive dense geodetic networks (the method of Pranis-Pranevich, electric computing machines);

2) Advances in the manufacture of geodetic instruments (mass production of large optical theodolites by domestic industry);

3) Advances in the training of cadres of geodesists.

Thus the system for establishing a state control geodetic network in the USSR changed over these 20 years (1928-1948). The change was and is accompanied by alterations of previously completed work or completion of previously established second-, third-, and fourth-order nets.

One may ask whether the presently adopted system for constructing the state geodetic network will be subjected to future changes.

How shall we establish projects for constructing the control geodetic network in such a way as to reduce alterations of completed nets to a minimum and to increase the duration of service of the control geodetic network in the USSR?

These questions are of vital interest to the geodesists of the USSR and are questions of great scientific and economic importance.

The answer to the first question is clear: as science and production work rise in level and develop higher requirements in respect to the geodetic basis, and as new methods and equipment for making measurements are developed, the system for constructing the state

geodetic network will be subjected to changes, even in the future. It is impossible to imagine forbidding endeavors directed toward the over-all improvement of the accuracy of the construction of geodetic networks.

The scientific requirements in respect to the accuracy and reliability of construction of basic geodetic networks are unbounded. They have given rise to the problem of studying the shape of the earth, the new problem of studying deformations of the earth's crust by geodetic methods, the need for systematic study of changes in the gravitational field of the earth, and the dynamics of changes in a geoid, like the shape of the earth.

The last two problems - the study of the deformations of the earth's crust and the dynamics of changes in the geoid - now pose the problem of construction of a principal geodetic network with the following principles:

1) The highest accuracy attainable in large state projects;

2) Repetition of measurements in the principal geodetic network, with reliable erection of markers.

The second principle has already been put into practice in respect to levelling, and the organization of repeated measurements in the principal triangulation is an urgent problem of the present.

The practical requirements of national cartography in respect to accuracy do not contradict the first principle at all.

Consequently, in the light of the new problems, we should change our view of the construction of a principal geodetic network somewhat. This control network must be established with the highest accuracy, with the erection of markers, with the prospect of making repeated measurements, and with the objective of subsequent determination of the coordinates of a number of points of the network, as a rule with new and more accurate methods and with a new system of construction.

Since the principal network is likewise a control for densifying nets, it should fulfill its role for as long a period as possible.

The methods for constructing densifying nets should be different from the method used for constructing the principal network.

The densifying nets constitute the geodetic basis for mapping the country and for carrying out various types of engineering and geodetic works; they should be calculated for lengthy periods of service, without making repeated measurements, without alterations, and with observations of the most advantageous systems of construction in economic respects, taking into account that such nets have a mass character.

Densifying nets must be established with reliable accuracy, and oriented to the largest scale of aerial photographic maps of the next stage of cartography (scale of 1:2,000) and in respect to density of points -- to the given stage of cartography (scale of 1:25,000-1:10,000), if there are no special requirements in a given region. We

believe that such an approach should be considered fundamental. By proceeding along this line, we shall increase the duration of service of the state control network with minimum outlays for its construction.

These considerations did not concern anybody in 1928, but they arose with special acuteness in 1948, when the first stage of mapping the country on a scale of 1:100,000 was completed and the State Service started the second stage of mapping (on a scale of 1:25,000-1:10,000).

With what accuracy and density will we have to construct the state control network for nationwide topographical maps on scales of 1:25,000-1:10,000?

It was in this way that the problem was placed before the Main Administration of Geodesy and Cartography, MVD, USSR in 1948.

It was clearly inexpedient to orient this network in 1948 on the accuracy required for maps on a scale of 1:10,000 as was done in 1928 and fixed, after 11 years had passed (that is, in the first stage of mapping), in the Fundamental Propositions of 1939, since the vigorous development in our country of geological prospecting and hydroelectric power projects, and the construction of industrial enterprises, cities, and populated points following World War II, required the compilation of large-scale maps on scales of 1:5,000-1:2,000 in growing amounts.

It is clear that in setting up dense geodetic projects, it was not necessary to orient ourselves on special-purpose maps for small areas on scales of 1:1,000-1:500 and 1:200. However, the mapping of a number of large industrial regions on a scale of 1:5,000 is no longer a longe-range prospect, but a present fact.

Although the state geodetic basis was orientated to a scale of 1:10,000 in accordance with the scheme of F. N. Krasovskiy in 1928 and the Fundamental Propositions of 1939, which ensured a mean square error in the mutual positions of adjacent points of any order of the network of ± 0.3 meters, now, with the trends toward development of the third stage of mapping, the newly-established geodetic basis must be oriented toward a scale of 1:2,000 (as the largest in the third stage of mapping).

It was proved in our work Novyye sistemy postroyeniya geodezicheskikh setey [News Systems for Constructing Geodetic Networks] (published in 1952) ([2], page 8), that dense nets of the new construction in accordance with the Fundamental Propositions of 1948 (they were retained in the Fundamental Propositions of 1954) satisfy the requirements of dense maps on a scale of 1:2,000 if a mean square error of ± 0.06 meters is maintained in the mutual positions of adjacent points.

Let us present here the computational justification of this important initial index.

Let us take the mean square error in the position of point P as determined by geodetic referencing, that is, from the surveying traverse KP (Figure 1) equal to ± 0.2 millimeters on the map, which will correspond to a distance of $m_p = \pm 0.4$ meters with a scale of 1:2,000.

Then, the weakest point K of the surveying geodetic basis AKB, on which the surveying traverse KP can rest, should be defined with a mean square error at least half that of point P, that is, $m_K = \pm 0.2$ meters.

In turn, the traverse of the surveying geodetic basis AKB should rest upon the state geodetic net ABC..., in which the mean square error in the mutual position of adjacent points (for example, of point B relative to point A) for any order of the state network should be one third that for point A, that is, equal to $m_B = \pm 0.06 - \pm 0.07$ meters.

The coefficient of the increase in accuracy of the state control geodetic network relative to the net of the surveying geodetic basis must be taken to be equal to 3 (not 2), because the state geodetic control net serves as a basis not only for topographical maps, but is often the starting point for the development of special geodetic nets used in different geodetic engineering measurements.

Therefore the state control geodetic network should be made as precise as possible.

Following the same procedure of computation, the mean square error in the mutual position of adjacent points of the state control network of any order, for maps on a scale of 1:10,000, is equal to $\pm$ 0.3 meters (which is maintained in the construction of the state control geodetic network according to the Krasovskiy scheme of 1928 and according to the Fundamental Propositions of 1939).

The Fundamental Propositions published in 1954 and the Instructions for First-, Second-, Third-, and Fourth-Order Triangulation issued in 1954-1955, do not indicate the map scale on which the accuracy of the new network is to be oriented, they do not give the theoretical and computational justification of this construction, and they do not fix the mean square error for determining the weak sides and the mutual position of adjacent points. However, theoretical and experimental studies by Soviet geodesists conducted in 1950-1954 showed that an increase of 5 times in accuracy is ensured in a dense net constructed in accordance with the Fundamental Propositions of 1954 with the above errors in angular measurements, as compared with the indexes of the nets fixed in the Fundamental Propositions of 1939. In other words, a mean square error of $\pm$ 0.06 meters is maintained in the mutual position of adjacent points in second-, third-, and fourth-order nets, and in a dense network of second-order triangulation the weak sides are determined with a mean relative error on the order of 1:250,000.

Thus, raising the accuracy of angular measurements by 2 1/2 times and, in addition, the designed precision of the dense construction of the nets increasing their accuracy by 2 1/2 times (with a joint strict adjustment of the nets) -- and on the whole this leads to a fivefold increase in the accuracy of the nets.

The accuracy prescribed by the Fundamental Propositions of 1954 for the geodetic network is much above that needed as the basis of the state topographical maps of the second stage of mapping on scales of 1:25,000-10,000, the basis on which the efforts of the State Geodetic

Service of the USSR are now concentrated. It is obvious that dense networks constructed according to the Fundamental Propositions of 1954 will fully satisfy the third stage of state mapping on scales of 1:5,000-1:2,000 in respect to accuracy.

In this case, the state control geodetic network is guaranteed a long period of service.

It is frequently asserted that the dense second- to fourth-order nets stipulated in the Fundamental Propositions of 1954 will satisfy the requirements of any large-scale mapping. Such statements are without grounds, as may be seen from the computations presented above.

It is appropriate to state that there is no need at all to orient the state geodetic network on mapping on scales of 1:200, 1:500, or 1:1000, as we must bear in mind that maps on these scales will be selective for a long time and will include comparatively small areas.

In setting up a program for constructing the state geodetic network, however, it is essential to provide a solution of the question of how to establish the geodetic basis for mapping, for large-scale maps (in selected places where needed), and how such special geodetic nets should be tied in with the state networks.

This problem is specially acute for city areas in which the city geodetic control net should be set up with the proper perspective and will not require revisions for lengthy periods.

As is well known, the scale of maps of populated parts of cities has been set at 1:500.

Following the procedure of computation set forth above, the mean square error in the mutual position of adjacent points of the geodetic basis should be maintained at no more than $\pm$ 1.5-2 centimeters in city areas.

Some geodesists have expressed the opinion that the state network specified by the Fundamental Propositions of 1954 can be used for cities, too. It is clear that this is a mistaken opinion.

However, the way out of this position is also clear: it will be necessary to construct special city nets for cities - of dense construction with sides of small length; by holding angular measurements to the accuracy specified for the dense state networks, it will be possible to maintain relative errors in the mutual position of adjacent points to the order of 1:200,000.

In order to maintain an accuracy in the mutual position of the points in this case to the order of $\pm$ 1.5-2 centimeters, it will be necessary to adopt lengths of the sides of the principal control net for the city on the order of 3-4 kilometers.

From this standpoint, the construction of the previous city principal nets, with sides on the order of 10-15 kilometers (up to 1940) and later on the order of 6-10 kilometers, was not well founded.

The Fundamental Propositions of 1954 essentially fail to provide a solution for the problem of constructing city triangulation nets, and, in view of the vigorous increase in the number of cities in the USSR and the expansion of their areas, this is an important shortcoming. A transition from the dense state networks to the city nets must be provided for in the program for the construction of state control networks.

Thus, establishing the necessary accuracy in the construction of the state geodetic control network is of fundamental importance and the solution should be closely connected with prospective mapping and with the system for constructing nets.

The system for constructing the state control geodetic network should maintain internal consistency, in respect to accuracy, in transitions from one order to another, from the principal network to densifying nets.

However, this consistency has not been maintained in the proper manner in the Fundamental Propositions of 1954.

It is well known that the scheme of F. N. Krasovskiy and the Fundamental Propositions of 1939 provide that first-order strips have a mean relative error in the weak sides of 1:100,000 ($\pm$ 0.3 meters in the mutual position of adjacent points), while the strips of the new construction specified in the Fundamental Propositions of 1954 are 1:150,000 ($\pm$ 0.15 meters in the mutual position of adjacent points when s = 20-25 kilometers).

It is clear from this that the points of the first-order strips of the previous and the new constructions cannot serve as the principal basis for the dense second-order nets of the new construction, which have a mean relative error in the weak sides of 1:250,000 ($\pm$ 0.06 meters in the mutual position of adjacent points). These considerations were stated by us in the work published in 1952 ([2], page 9).

However, the Fundamental Propositions of 1954 and the Instructions on Triangulation published by the GUGK in 1954 do not take into account this incompatibility in the accuracy of the strips of first-order triangulation and of the dense second-order net and do not provide any measures for eliminating this incompatibility, either for the period for developing the nets or for the future.

Another shortcoming of the Instructions of 1954 is that the mean square error of the base sides of the dense second-order net has been set at 1:250,000 (that is, the tolerance has been doubled), or only at the level of accuracy for determining the weakest sides in the dense second-order net.

This standard was clearly established without taking into consideration the designed special features of the dense nets in which, due to the large number of excess links, ([4], page 5) an increase in accuracy of 2 1/2 times is ensured over the triangulation strips (with the same accuracy of angular measurements).

It is clear that the base sides in a dense second-order net should be determined with an accuracy not less than 1:500,000. This accuracy can be maintained with ordinary base measurements with invar

tapes (a transition to direct measurement of the sides or permitting an increase in the base nets of not more than 2 times) and with measurements of distances made by precision optical range finders (already done in practice).

We note also that the distribution of bases in the dense second-order net such that there are no more than six to seven triangles between the remote side to the bases, is not essential. This requirement in the Instructions of 1954 is the product of former views on the dense nets, whose accuracy was judged on the basis of the triangulation strips. In fact, as studies have shown, the dense nets have greater uniformity in respect to the accuracy of their individual parts than the strips; and the character of the accumulation of errors in these nets is quite different, that is, it accumulates more slowly than in the strips.

Starting with these considerations, it is wholly possible to distribute the bases, for example, on the edges of the blocks of the dense second-order net which are included in first-order polygons (with dimensions of 200 x 200 kilometers), which can be done expediently for tying in the principal network.

We note still another shortcoming. Many steps (four orders) are retained when nets are constructed in accordance with the Fundamental Propositions of 1954.

As already noted in our work ([3], pages 58-59), a densifying net developed inside the triangles of dense second-order nets (s = 10-15 kilometers) should be of one order, that is, it would be expedient to replace third- and fourth-order nets with nets of a single order. (In the work [3], the author calls them first-order nets.)

The former multi-order constructions of control nets were the products of the technology of that time, chiefly the shortage of high-precision instruments and also of qualified engineering cadres, but these conditions have changed materially by this time.

Thus, the construction of state control nets in accordance with the Fundamental Propositions of 1954 has a number of shortcomings which were previously noted in part; it is obvious that this system of construction must be revised to eliminate these shortcomings.

A number of fundamental propositions which should be adopted in forming a basis for constructing state geodetic control nets have been examined in our works published in 1957 [3] and in 1958 [4].

Let us add the considerations stated above, after formulating them in brief form, to those propositions.

1) The system for constructing the state geodetic control network should be oriented toward the highest accuracy attainable with contemporary methods and equipment for making measurements (in mass projects of national character).

2) It is expedient to construct geodetic nets in accordance with the principle of density, thus ensuring a large number of excess links and, consequently, high accuracy.

This proposition should, of course, be extended to linear geodetic nets (optical range finder and radar).

Therefore, it is simply impossible to agree with tendencies to construct, for example, optical or radio range finder polygonometry without excess links. Systems for introducing excess links into geodetic nets can be most varied, but these links should be such that they ensure the observation of the principles of density and highest accuracy.

3) It is expedient to construct the principal control nets on the base of blocks of dense first-order networks by forming dense linear-angular nets of large figures whose vertices rest on Laplace bases and azimuths.

This proposition was not formulated clearly enough in our preceding works [3] and [4]. The sense of this proposition is stated more clearly in this formulation.

This proposition is essentially a development of the method worked out by Gel'mert and Krasovskiy for constructing and adjusting a principal control net for modern conditions in which dense second-order nets inside polygons of first-order triangulation must attain the same level of accuracy in angular measurements as first-order triangulations and surpass the triangulation strips by 2 1/2 times in respect to the designed precision of construction. (Thus modern second-order nets should be called first-order nets).

As we have already noted in our work [4], the construction of a principal control net in the form of strips of first-order triangulation has a historic basis, at first only in the form of grade measurements, then the work of mapping the country required a system for forming polygons from strips of first-order triangulation as the primary geodetic basis with angular measurements of the highest accuracy.

The dense nets constructed inside first-order polygons are considered to be the secondary basis, and the angular measurements in these nets are made with tolerances 2 1/2 times as large as in the strips of first-order triangulation.

Therefore it is natural that the construction and adjustment of first-order polygons should be separated up to this time from the construction and adjustment of the dense nets within the polygons.

As is well known, the Gel'mert-Krasovskiy method calls for making the transition from a system of first-order strips resting on Laplace bases and azimuths to a system of calculated lengths and azimuths of the diagonals of these strips, then to the formation of systems of polygons from them (Figure 2).

At present, in view of the changing conditions for constructing dense nets inside the polygons, it is expedient to develop the Gel'mert-Krasovskiy method further and to make the transition from a system of

blocks of dense first-order networks to a system of calculated lengths and azimuths of the diagonals and to forming dense nets of large figures from them which rest on Laplace bases and azimuths (Figure 3).

4) A multi-order construction of the nets is inexpedient. It is expedient to densify the dense first-order net with nets of just one order.

5) The system for constructing geodetic control nets should be changed in the process of the development of methods and equipment for making measurements and computations at definite stages, at the same time preserving the continuity between previously completed networks and using them as long as possible.

6) The system for constructing state geodetic nets should ensure minimum expenditures of personnel, money, and time on establishing them, at the same time maintaining the highest accuracy in the construction of the nets and ensuring the longest possible periods of use for them.

II. A New System for Constructing the State Geodetic Control Network of the USSR

Starting with the fundamental propositions stated above, it will be expedient to adopt a scheme for constructing the principal geodetic basis in the form of a dense linear-angular net of large figures which have sides of 100-140 kilometers, whose vertices rest on Laplace bases and azimuths, and which are derived from adjustment of blocks of dense first-order networks (second-order according to the classification of 1954) with sides of the triangles $s = 0\text{-}15$ kilometers, with 200 x 200 kilometer blocks, and with a mean square error in the measurements of the angles of $\pm 0''.7\text{-}0''.8$ according to the scheme of Figure 3.

For this purpose it will be expedient to shift the bases in the presently accepted scheme for constructing dense nets to the periphery of the blocks of the dense first-order network (Figure 3), providing that they be measured with an accuracy of 1:1,000,000. The accuracy for determining Laplace dual azimuths should be on the order of $\pm 0''.7$.

With such a system for constructing linear-angular nets of large figures whose vertices rest on Laplace bases and azimuths, the systematic errors in the dense first-order network will be reduced noticeably. Only in the case of such construction will it be possible to apply formulas for random errors subordinate to the law of normal distribution when evaluating accuracy.

Calculations made with this type of formulas yield the following indexes for a dense first-order network ($s = 10\text{-}15$ kilometers) in the weakest places (with initial errors in measurements given above):

the mean square error of mutual position of adjacent points

$$M = \pm 5.6 \text{ centimeters,}$$

the mean square error of the weak sides

$$\frac{m_s}{s} = 1{:}250{,}000\text{-}1{:}300{,}000$$

the mean square error of the azimuths of the sides

$$m_\alpha = \pm\, 0''.7$$

For the principal network of large figures (L = 100-140 kilometers) we have the following indexes:
longitudinal and transverse displacements:

$$m_{L,q} = \pm\, 12\text{-}15 \text{ centimeters},$$

the mean square error of the interior sides of the large figures

$$\frac{m_L}{L} = 1{:}9 \times 10^5,$$

the mean square error of the azimuth of the interior sides of the large figures

$$m_\alpha = \pm\, ''.2\text{-}0''.3.$$

The accuracy of determination of the exterior sides of the large figures and their azimuths will be $\sqrt{2}$ of the accuracy of the interior sides and azimuths.

After balancing the 200 x 200 kilometer blocks of the dense network individually, however, we shall obtain two values for the lengths of the exterior sides and their azimuths (at the junctions of the blocks). The mean weighted value of these two determinations will ensure an accuracy of $\sqrt{2}$ times the preceding figure and, consequently, the same as the interior sides of the large figures.

Thus the network of large figures will be of uniform accuracy.

This process for forming a linear-angular network of large figures in adjusted blocks of a dense first-order network, as mentioned previously, is analogous to the well-known process of forming the polygons of the astrogeodetic net from diagonals derived from adjusting individual links of first-order triangulation, as suggested by Gel'mert and developed by F. N. Krasovskiy (Figure 2). Therefore, when our suggestion on forming large figures in a dense first-order network from the diagonals whose vertices rest on Laplace bases and azimuths (Figure 3) is identified with the suggestions of Hungarian geodesists, we naturally protest against such identification.

As is well known, when constructing a principal control network from strips of first-order triangulation, forming polygons whose sides are 200 x 200 kilometers (according to the scheme of Figure 2), we have (when $m = \pm 0''.7$):

$$\frac{m_s}{s} = 1:150{,}000$$

$$m_{L,q} = \pm 0.6 \text{ meters}$$

$$\frac{m_L}{L} = 1 / 330{,}000$$

$$m_{\alpha_L} = \pm 0''.6,$$

and for the angles at the vertices of the polygons

$$m = 0''.6 \times \sqrt{2} = \pm 0''.85.$$

Thus all the indexes which characterize the accuracy of the construction of the principal network with the aid of blocks of the dense first-order network are about 2 1/2 times more accurate than in the first-order strips and the polygons formed from them.

The effectiveness of the new system for constructing the principal basis stems from this.

If we develop a dense linear triangulation in the above 200 x 200 kilometer blocks with lengths of the sides s = 10-15 kilometers with mean square errors in measuring the sides of 1:200,000 then the experimental calculations made in the department of higher geodesy of the MIIGA ik [sic] in 1959 indicate that the following mean square errors would be obtained for large figures (L = 100-140 kilometers):

longitudinal displacement: $m_L = \pm 10$ centimeters,

transverse displacement $m_q = \pm 38$ centimeters,

azimuths of the weak side of small figures $m_\alpha = \pm 1''.12$.

In case the sides are measured with an error of 1:400,000, we shall have (for large figures)

longitudinal displacement: $m_L = \pm 5$ centimeters,

transverse displacement: $m_q = \pm 19$ centimeters.

These indexes are already close to angular triangulation when $m = \pm 0''.8$ (with the same length of sides), even though the transverse displacement in the linear triangulation is almost 4 times that of the longitudinal displacement.

It is obvious that the combination of linear and angular triangulation is the sole proper way for constructing dense first-order networks and dense nets of large figures derived from them with the highest accuracy. It is understood that it is possible to combine angular and linear triangulation with polygonometry (optical location finder and radar), but with a sufficient number of excess links.

An analysis of the problem shows that in order to retain continuity with dense nets previously completed in accordance with the Fundamental Propositions of 1939 and 1954 (with the same length of sides) and maintaining the accuracy stated above in the construction of the principal network for dense first-order nets, it will be essential to retain the length of the sides $s = 10\text{-}15$ kilometers.

With such a density of points in a dense first-order network (averaging one point per 150 square kilometers), the nation will be provided with a single system of coordinates at a sufficiently rapid rate and it will be possible to develop, quite conveniently, a single-order densifying net on that basis (in place of the third- and fourth-order nets accepted in the present construction).

As is well known, there are suggestions for replacing second-, third-, and fourth-order nets with a single-order network with length of sides of 7-8 kilometers (averaging one point per 50 square kilometers) and even to calling it a dense first-order network.

In our opinion, this suggestion is another extreme of the presently accepted multi-order construction.

As a matter of fact, in such a single-order network, the number of first-order points in the same area will be increased 3 times, and developing every point in this network as a first-order point will require great effort and the concentration of a large number of skilled personnel and precision instruments. It is scarcely proper to complicate the work of constructing the dense first-order network which is supposed to serve as the basis for establishing the principal control network, according to the method previously stated. In our opinion, the lengths of the sides of the dense first-order network in some regions of difficult access (mountainous, mountainous taiga, and others) can be increased up to 20 kilometers.

It would be expedient to achieve further densification of the dense first-order network with a single-order net. One asks, with what density should one construct this net?

This is a problem of great technical and economic importance, and the answer should be based on comprehensive studies of different variants for constructing the densification nets.

It was stated previously that it is expedient to orientate the density of the points on the current stage of mapping, but still taking into account continuity in transitions to the following stage, since it usually begins to develop in the period of the current stage.

In this connection, we believe that the following variant for constructing the network merits attention.

A dense first-order network (s = 10-15 kilometers and $m = \pm 0''.7$-$0''.8$) is densified with a single-order network of the second order with lengths of the sides s = 4-5 kilometers (averaging one point per 20 square kilometers) and with a mean square error in angular measurements $m = \pm 1''.5$.

This second-order net has been developed with calculations and methods such that it will be possible wholly to avoid the construction of towers, except simple pyramids.

The achievement of this requirement was facilitated by the following factors: 1) the small length of the sides (s = 4-5 kilometers; 2) the possibility of considerable variability in the shape of the figures (triangles), since the second-order net rests on a precise first-order network; 3) the comparatively low required accuracy in angular measurements ($1''.5$).

In fact, in a level, open locality with distances of 4-5 kilometers between points, visibility between adjacent points (simple pyramids) is ensured from the ground (from tripods).

In hilly, open localities, due to the considerable variability permitted in the figures, it is possible to avoid obstacles and ensure visibility from the ground; thus it is possible to limit construction to simple pyramids.

As for forested regions, even with any length of sides (4, 7, and 12 kilometers), it will be necessary to build towers 25 or more meters high. Therefore it will be necessary to develop second-order nets, like the first-order network, in these regions with optical and radio range finder methods of polygonometry in order to reduce the heights of towers.

The length of the sides of the second-order net can be increased to 7-8 kilometers in regions of difficult access; but in open or semi-open regions, particularly if they are industrial and thickly populated, the length of the sides must be 4-5 kilometers (one point per 20 square kilometers).

Preliminary calculations show that, for example, for a 200 x 200 kilometer block of the dense network in open and semiopen regions, the total meterage required for building the towers for the dense first-order network will be 1.7-2.0 times cheaper with the first variant, which calls for constructing nets of two orders (s = 10-15 kilometers and s_2 = 4-5 kilometers), than with the second variant, which calls for construction of a single order (s = 7-8 kilometers.

If, however, we consider the construction of simple pyramids in the second variant, then with the same density of points in each variant (50 square kilometers) for purposes of comparison, the total volume (meterage) required for building towers will be 1.2 to 1.3 times cheaper with the first variant than with the second.

It is this which gives rise to the technical and economic advantage of the first variant over the second variant, inasmuch as it is well known that outlays for the construction of towers account for 2/3 the total outlays for establishing a geodetic network.

It is understood that only preliminary calculations are presented here.

It is necessary to make more complete calculations of expenditures of manpower and money for the first and second variants for constructing the nets, including outlays for establishing the geodetic control survey, since it has now begun to play an important role in the control of each surveying trapezium.

Our suggestions in regard to the construction of a geodetic control net (with the first variant) will ensure the continuity and the use of previously completed third- and fourth-order densification nets (s_3 = 5-8 kilometers and s_4 = 2-4 kilometers).

Let us discuss the continuity and use of strips of first-order triangulation. It cannot be denied that the strips of first-order triangulation have played an outstanding role in determining the Krasovskiy ellipsoid and in establishing a single system of coordinates over the whole of our country.

The establishment of strips of the first order at that stage of the development of geodetic control nets was proper and unavoidable.

It was likewise wholly proper to endeavor to complete the construction of polygons from strips of first-order triangulation in the northern and northeastern regions of the USSR in order to extend a single system of coordinates to these regions, too, so far as dense nets of first-order triangulation were established there over a prolonged period of time.

In regions in which dense first-order networks (second order according to the classification of 1954) are being developed at present, it is obvious that there is no necessity for decreasing the dimensions of the first-order polygons or even altering previously completed first-order strips which do not satisfy the requirements of the Instructions of 1954, since it will be expedient to establish the principal control network in regions of the development of dense first-order networks from blocks of dense nets in accordance with the method mentioned previously.

Thus the establishment of the principal control network from blocks of dense first-order nets is a new, second stage in the establishment and development of the principal control network for which we must prepare ourselves and which must be introduced gradually even in the period of the first stage of establishing the principal control network.

As is well known, mapping of the nation is being developed by stages (as mentioned previously).

The establishment of the principal control network which will satisfy scientific and practical requirements should also be developed in stages, but of longer periods (for maximum utilization of the geodetic basis).

Let us discuss briefly the adjustment of the control nets of the new system of construction.

The principles of this adjustment were set forth in our work [4].

Let us note here that every 200 x 200 kilometer block of the dense first-order network, which includes about 400 points (on the order of 600 triangles), is adjusted as a whole, as a semifree network resting on Laplace bases and azimuths, separately from neighboring blocks. Previously completed first-order strips are included in the common adjustment of blocks of the dense first-order network after being given suitable weights.

The blocks of the dense first-order networks are adjusted by the Pranis-Pranevich method.

Then the sides and the angles of the large figures in the adjusted blocks of the dense network are calculated (in analogy with the calculation of the diagonals of the strips for polygons of first-order triangulation). The dense linear-angular network of large figures which has been formed is regarded as a directly measured net.

The dual value of the lengths of the sides in the figures of adjacent blocks can be reduced to a single value by computing the mean weighted value. On the other hand, the dual values of the azimuths of these adjoining sides will be eliminated by introducing conditions of the horizon and conditions of the sums of the angles in the large figures of the principal network (with common adjustment of the dense network of large figures).

Adjustment of the dense network of large figures is done as a whole, strictly on the accepted reference ellipsoid, as the astrogeodetic network of dense construction with measured angular and linear elements.

For example, the number of points in the dense network of large figures for the European part of the USSR amounts to about 600 (about 900 triangles). In the future the number of points of large figures will come to about 2,000 for the entire USSR when the development of the dense network of triangulation is completed over the entire area of the USSR.

It is wholly obvious that still another method for common and strict adjustment of the entire dense first-order network by the Pranis-Pranevich method with division of the network into parts (into 200 x 200 kilometer blocks) has not been excluded.

In this case, too, the first stage of individual adjustment of the dense network by blocks (200 x 200 kilometers) will also turn out to be useful.

Let us dwell briefly on the establishment of fundamental Laplace azimuths and initial lengths of the sides in the principal control network.

In order to make the principal control network more precise and to reduce systematic factors, it is expedient to introduce fundamental Laplace azimuths (also fundamental astronomical latitudes and longitudes), and also fundamental determinations of base sides in the large figures of

the network with lengths up to 100 kilometers, either with an indirect method, for example, by making highly accurate optical or radio range finder traverses or by direct measurements with the aid of light or radar position finder methods every five to eight blocks, that is, every 1,000-1,500 kilometers (Figure 4).

Inasmuch as the sides of the large figures of the dense network are determined with a relative error of $1:9 \times 10^5$, the fundamental base sides with a length of 100 kilometers should be determined with twice that accuracy, that is, on the order of $1:1.8 \times 10^6$. The problem of determining the fundamental azimuths and lengths of sides merits special study.

As may be seen here, the principal control network established by the method described previously is a dense astrogeodetic network of points located 100 kilometers from each other. It should be combined with a dense gravimetric network of points in which it would be expedient to separate fundamental gravimetric points compatible with the above-mentioned fundamental astronomical points.

The principal astrogeodetic network of the new construction will be used in the future for deriving new measurements of the terrestrial ellipsoid. It will also permit a comprehensive approach to the actual investigation of horizontal displacements of individual parts of the earth's crust similar to the manner in which vertical displacements of the earth's crust are now being investigated with repeated high-precision levelling.

In the future, geodesists will have at their disposal more accurate and more effective methods for making measurements than they do at present, and they will be able to make repeated measurements in some form or other in the principal astrogeodetic network now being established, thus obtaining valuable data through comparing the results of the measurements for studying deformations of the earth's crust and for changes in the shape of the earth.

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FIGURE APPENDIX

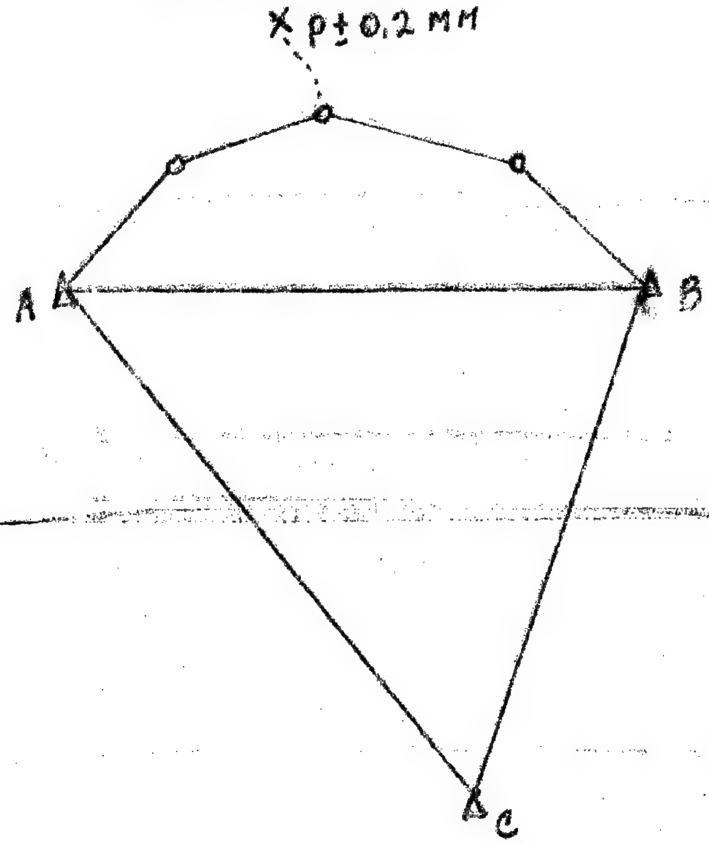

Figure 1

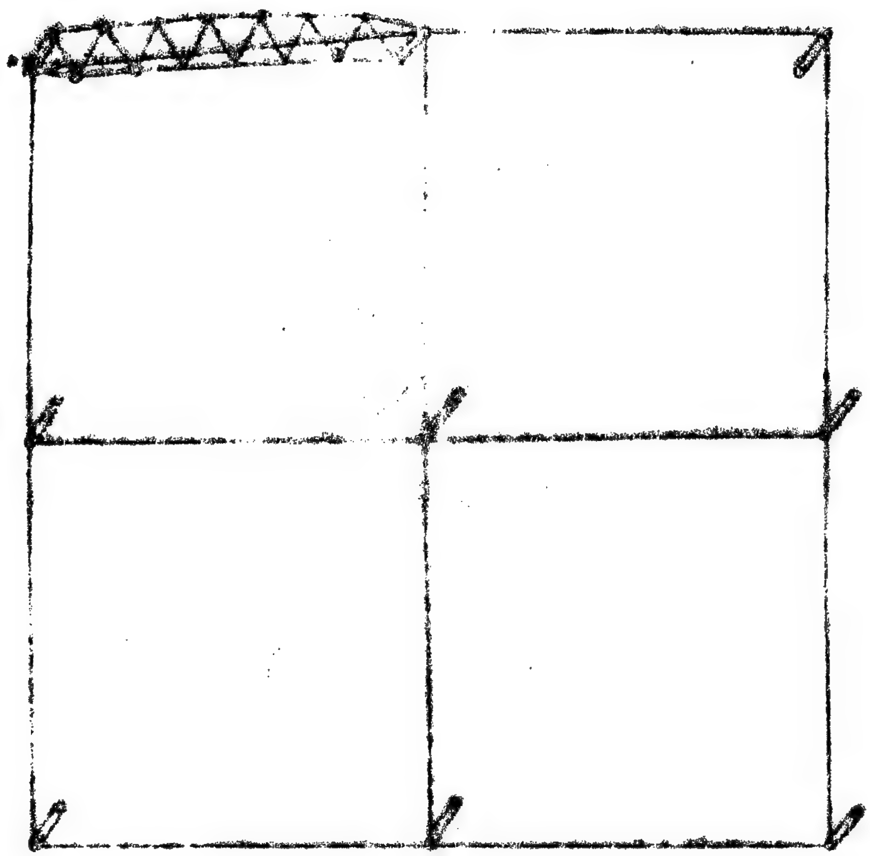

Figure 2. Symbols used in the bases are like those of Figure 3

o Laplace points $(\varphi, \lambda, \alpha)$

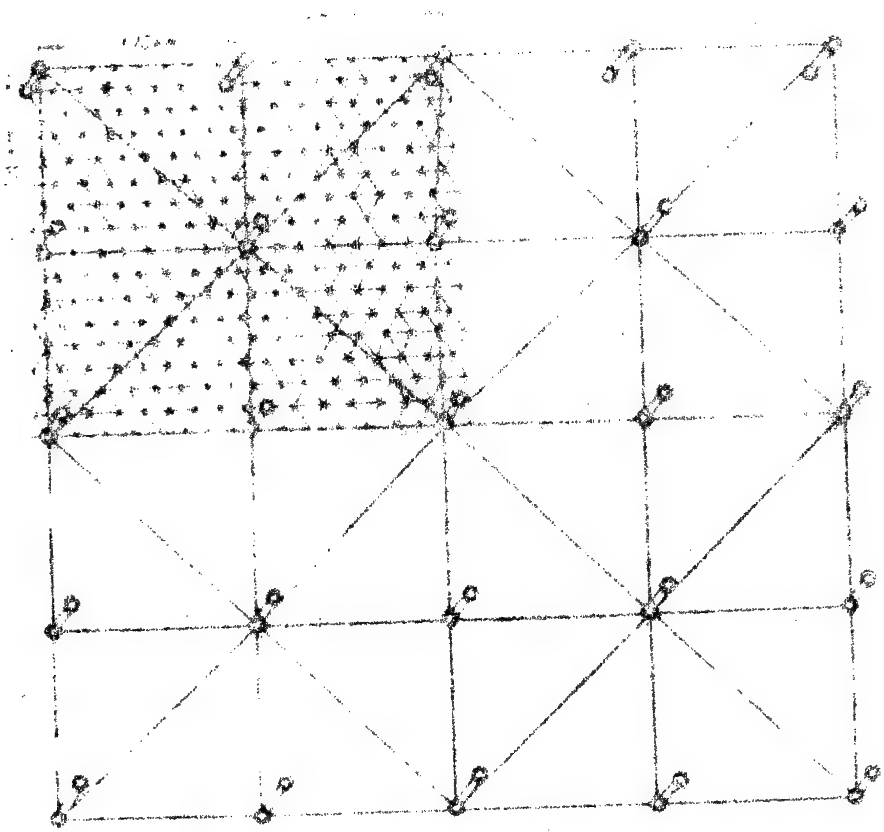

Figure 3

Dense network of first-order triangulation s = 10-15 kilometers

Bases

Laplace points $(\varphi, \lambda, \alpha)$

Principal control network of large figures formed from adjusting a dense first-order network s = 100-140 kilometers.

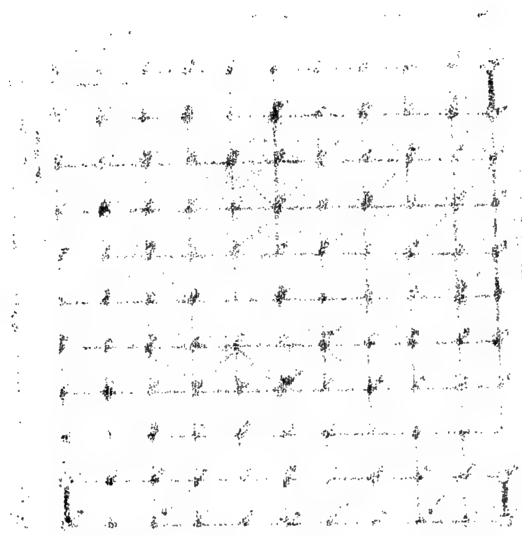

Figure 4

Bases

Laplace points $(\varphi, \lambda, \alpha)$

Fundemental base sides

Fundamentel
Laplace points $(\varphi, \lambda, \alpha)$

Principal control
network of large
figures
s = 100-140
kilometers

V. MODERN MEANS AND METHODS FOR GEODETIC MARRIAGE OF CONTINENTS

Pages 89-101

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The basic tasks of higher geodesy--determination of the dimensions and the shape of the earth and the spatial coordinates of points on the earth's surface in terms of a single coordinate system--require the geodetic marriage of continents, since the position of the ellipsoids on which triangulation has been developed relative to each other and to the center of inertia of the earth is not known. Such links are also necessary for the compilation of maps, for navigation, rocket launchings, studies of shifts in continents, irregularities in the rotation of the earth, et cetera.

1. Marriage of Continents by the Triangulation Method

This method is very simple and consists in constructing triangles or rectangles with large sides whose solution requires the application of the complete Legendre formulas. The maximum distance of a link is determined here by the formula

$$S = 3.89\ \text{KM}\ (\sqrt{h_1} + \sqrt{h_2})\ \text{M} \quad \text{or} \quad h_m = S^2_{KM}:61 \qquad (1)$$

Then, when $h_1 = h_2 = 2,500$ meters, $S = 3.89\ (50 + 50) = 389$ kilometers. Consequently, necessary factors here are points at great heights, powerful light sources, and good visibility, which limits the possibility of using this method. (When connecting the Baleares Islands with Spain in 1804-1825, J. Biot spent 6 months on the Desierto Peninsula before he saw a light on Ivis Island at a distance of 160 kilometers.)

This method was used for the first time in 1783-1789 by English and French geodesists headed by F. Cassini to connect the grade measurements of France and England across the English Channel (100-150 kilometers) [1]. In 1879 Spanish geodesists connected Europe and Africa across Gibraltar ($S < 54$ kilometers). In 1872 J. Perrier's project connected two points in Spain with two points in Algiers by means of geodetic quadrangle whose longest side was 270 kilometers (Figure 1) [1]. In order to increase the accuracy, the connecting points should have been Laplace points.

The longest triangulation leg on dry land was one of 370 kilometers (Shasta--Makdermik) in traversing the arc along the 39th parallel in the western part of the United States in 1871-1898. (The longest triangulation leg in the USSR is El'bruz--Godorezi with a distance of 234 kilometers.)

This method can be used to connect the networks of the USSR and the United States by the Bering Gulf and Diomede and King Islands (project of graduate of the NIIGAIK, L. Bolbas) and also to connect the northern islands with the continent but its possibilities are restricted by distances of 250-300 kilometers and also by visibility conditions.

2. Marriage of Continents by a Method of Dynamic (Rocket) Triangulation

This method was suggested in 1920 by M. Schnauder and in 1924 by G. Athanasiades for connecting Europe and Africa by triangulation. It was impossible to complete the connection by the triangulation method across the island of Crete, since the distance from the island of Crete to Africa was 300-400 kilometers, the height of the mountains on Crete was 2,000-2,500 meters and on the coast of Africa only 200-500 meters.

This method was based on observation of moving sight targets (PVTs) and the construction of "geodetic hexagons" (Figure 2). In the figure A B Z_1 Z_2 C D, the points A and B are initial points; and D determinable; and Z_1 and Z_2 auxiliary, over which the sighting targets are placed (hydrogen balloons or rockets). At points A, B, C, and D angles α, β, γ, δ, then α_2, β_2, γ_2, δ_2, are simultaneously measured or photographed. The coordinates of the points Z_1 and Z_2 are obtained from solving straight lines of intersection, and points C and D from solving the problem of Hansen or Potenot (with three targets). In order to obtain surplus data, the length and azimuth of leg CD are measured, which gives the conditions of the bases and azimuths. If three sighting targets are observed and 12 angles are measured, then two of them are surplus.

The distance of transmission here is determined by the formula

$$\sum S = 7.78\,(\sqrt{h_m} + \sqrt{H_Z}), \qquad (2)$$

where H_Z is the height of the target. When h_m = 1,000 meters and H_Z = 4,000 meters, $\sum S$ = 738 kilometers.

When processing and adjusting a geodetic hexagon with distances of more than 100 kilometers, it is expedient to use the method of V. V. Popov of projections on a Legendre plane and to calculate the coordinates of the intersections in a Gauss projection on a sphere by the author's formulas [3]

$$\operatorname{tg}\Delta\lambda_1 = \frac{A + B\operatorname{ctg}\alpha_2 - C}{A_1 + B_1\operatorname{ctg}\alpha_2 - C_1\operatorname{ctg}\alpha_1}; \quad \alpha_1 \approx A_1 \quad \alpha_2 \approx A_2 \qquad (3)$$

$$\operatorname{tg}\varphi = \cos\Delta\lambda_1 \operatorname{tg}\varphi_1 + \sec\varphi_1 \sin\Delta\lambda_1 \operatorname{ctg}\alpha_1 = \cos\Delta\lambda_2 \operatorname{tg}\varphi_2 -$$

$$- \sec\varphi_2 \sin\Delta\lambda_2 \operatorname{ctg}\alpha_2, \qquad (4)$$

$$A + \operatorname{tg}\varphi_1 \cos\varphi_2; \quad B = \sin\Delta\lambda; \quad C = \sin\varphi_2 \cos\Delta\lambda;$$

$$A_1 = \sin\varphi_2 \sin\Delta\lambda; \quad B_1 = \cos\Delta\lambda; \quad C_1 = \sec\varphi_1 \cos\varphi_2 \qquad (5)$$

For this method the author has simplified the methods for solving triangles with sides up to 800-900 kilometers.

The use of triangulation with moving sighting targets became practically feasible when a theodolite with photographic registration of radio pulses (radiophototheodolite) was invented in Germany in 1942-1943. The Germans used: a) a large Ascania optical theodolite; b) a receiver-transmitter radio station with a motor-generator set; c) an amplifying relay; and a device for processing the film. The Canadians used a Wild T-3 optical theodolite, and the Russians used an OF-02 theodolite with a camera attachment [4], [5].

In 1944 this method was used to establish a connection between England and Normandy (150-180 kilometers) and a connection between Denmark and Norway in 1945 (150 kilometers). The United States used this method to connect Florida with the island of Cuba (250 kilometers), the Bahamas with the island of Cuba, Haiti and Jamaica with each other and with the continent. The longest leg, Turquino (Cuba) -- Macay (Haiti), was 345 kilometers [4]. In 1953 the moving sighting target was used to connect the Pine River Observatory with triangulation points at distances of 250 kilometers. With 32 to 54 determinations, the mean square error of a point, by convergence of the results, was from $\pm$ 3 to $\pm$ 5 meters, and with a control triangulation strip the error in the last point was $\pm$ 1.5 meters [5].

The minimum height of the moving sighting target is determined by the well known formula

$$H_Z = (0.257\ S_1 - \sqrt{h_1})^2 \qquad (6)$$

For Crete and Africa S_1 = 200 kilometers, h_1 = 200 meters, and H_Z = 1,400 meters, but for repeated observations the rockets should be launched to an altitude of about 4 kilometers. In Canada the rockets were launched from an airplane at an altitude of 4-5 kilometers.

Further development of this method is linked with the use of interference theodolites of the "electric eye" type suggested by Ye. Gigas in 1954. (An interference instrument was developed for the first time by academician V. P. Linik in 1946, but such instruments were used

only in astronomy in the USSR.) The Gigas interference theodolite would permit observing with infrared rays under poor visibility conditions and in fogs. In addition, further development is linked with radio direction finders [4]. The moving sighting target method is quite accurate and more promising than the ordinary triangulation method, but it is very complicated in an organizational sense and is limited to distances of 350 kilometers. A significant improvement in the accuracy of radio direction finders and the use of artificial earth satellites (ISZ) could greatly extend the limits of its application.

3. Marriage of Continents by a Radar Method

A pulse apparatus and the "method of transverse flights" are used for this purpose. In this method an airplane with an ultrashort-wave interrogator intersects a measured line several times, at about the middle and perpendicular to the line, and the sum of the inclined, curved-line distances from the airplane to ground stations located at the ends of the measured line is fixed visually or photographically every 2-3 seconds (Figure 3). The minimum sum of distances corresponds to the flight over the line. External intersection is used for short lines and the maximum difference of distances is found [7].

Meteorological sounding of the atmosphere with an airplane or sounding balloons is conducted at the same time. The necessary physical and geometric corrections are inserted as a result of measurements [6], [7], [8]. However, the procedure for introducing corrections has not been developed sufficiently, particularly for hyperbolic systems.

The range of propagation of ultrashort radio waves, taking refraction and diffraction into consideration, is expressed by the formula

$$S = 4.15\ (\sqrt{h_1} + \sqrt{h_2}), \qquad (7)$$

and the range of communications in the method of transverse flights

$$S = 8.30\ (\sqrt{h_m} + \sqrt{H}). \qquad (8)$$

For a maximum side of 920 kilometers, measured in the United States in 1946, H = 12.3 kilometers was obtained.

Pulse methods were used for the first time for determining the height of the ionosphere in the United States in 1925 (G. Bright and M. Tyuvo) and in the Soviet Arctic in 1932-1933 by M. A. Bonch-Bruyevich. In the war, from 1941 to 1945, they acquired wide application for locating airplanes and ships, and for bombing, navigation, and aerial photography. In 1945 the United States used the shoran pulse system in Italy for measuring great distances in geodesy with the transverse flight method. Analogous systems were developed in the Soviet Union [6], [7].

This method was used in the 1950s for establishing large radio geodetic networks in the United States, Canada, Australia, and the USSR over distances of 300-400 kilometers with an accuracy of 1:100,000-1:50,000, or close to the accuracy of first-order triangulation. Shoran was used to establish geodetic connections between Scandinavia and England; Asia Minor and Africa through Crete; England and Iceland; North and South America through the Great and the Small Antilles [6].

In 1955 the accuracy of the shoran system was increased by thermostating airplane equipment and the use of stabilizers with higher frequencies (the Hyran system). It was reported that it was used to connect the island of Crete with Africa, and Europe with North America. Twenty first-order points in Norway, England, Iceland, and Greenland were connected by quadrangles with a maximum distance of 884 kilometers with this system. The accuracy of measurement of distances was about 1:120,000. The author developed methods of solving triangles with large measured sides up to 800 kilometers for these methods of making connections [7]. Spatial linear intersections are a further development of these methods [9].

However, the azimuths of the sides are not determined precisely enough in radio geodesy. Therefore, when there is direct visibility, it is expedient to combine radar measurements with geodetic or astronomical measurements of angles or azimuths. Then, in connecting chains of islands, for example the Kuriles or the Aleutians, it is possible to apply "radio polygonometry" (Figure 4) or "azimuthal intersections" which are a generalization of A. I. Durnev's intersections for the ellipsoid. In the latter case it is sufficient to measure the forward and back azimuths at all points of the chain. On the other hand, measuring distances and the coordinates of the end points yields surplus data for adjustment.

When direct visibility is lacking, E. Sodano in the United States and G. Wolf in Germany suggested in 1953 [10] that moving sighting target triangulation be combined with radar distance measurements, which would increase the accuracy of the results and permit determining the azimuths of very long lines. Each line of this type gives rise to two equations.

$$\left.\begin{aligned} -(S_A+\delta S_A)\sin(\alpha_A+\delta_A-\alpha_S)+(S_B+\delta S_B)\sin(\alpha_S-\alpha_B-\delta_B)&=0\\ (S_A+\delta S_A)\cos(\alpha_A+\delta_A-\alpha_S)+(S_B+\delta S_B)\cos(\alpha_S-\alpha_B-\delta_B)-S&=0 \end{aligned}\right\} \quad (9)$$

Radar methods for connecting continents are suitable for distances up to 1,000 kilometers and promise high accuracy in the future. The successful application of radio methods for observing artificial earth satellites and rockets is a guarantee of this.

4. Marriage of Continents by Methods of Cosmic Triangulation

In these methods one does not observe rockets, as in rocket triangulation, but celestial bodies near the earth (the moon and artificial earth satellites). By comparing the geocentric coordinates of the moon, the parallax of which $\pi_C = 57'$ is quite large (Figure 5), relative to the center of mass (not to the center of the ellipsoid!), with observed topocentric coordinates one can determine the absolute spatial coordinates of the observer X, Y, Z or $\varphi', \lambda', \rho'$ or corrections to the approximate (astronomical) coordinates [15].

(It is also possible to obtain a single system of spatial coordinates connected with the center of inertia of the earth by a combined study of the general gravitational field of the earth and the results of astrogeodetic work on different continents [16], but discussion of this method is beyond the scope of this article.)

Determination of absolute coordinates by observations of the moon was not applied before the 20th century on account of the low accuracy of the observations and the coordinates of the moon. According to Brown's tables, the coordinates of the moon are obtained with systematic errors $\Delta\lambda$ and $\Delta\beta$ which are caused by irregularities in the rotation of the earth up to several seconds. On the other hand, an accuracy of 0".01 is required, since all the equations of errors contain the coefficient $\pi_C = 1:60^2$ and every error in observing the moon and its position is magnified 60 times [16], [14]. (For an earth satellite moving at an altitude of 1,270 kilometers, $\sin \pi = 0.85 \cong 50 \sin \pi_C$.)

Now that the accuracy of observations of the moon has been increased by photoelectric registration (1949), the corrections $\Delta\lambda$ and $\Delta\beta$ are found from systematic observations at a large number of observatories and more accurate positions of the moon are available (1944). Inasmuch as the observations of the moon are conducted by a differential method, the measurements of the parallax angle are not distorted by deviations of the plumb line, as distinguished from the calculated one [16].

There are four different methods of cosmic triangulation: a) observations of solar eclipses; b) observation of occultation of stars by the moon; c) photographic observations of the moon and stars; d) observations of artificial earth satellites [13].

a. A method for observing eclipses to determine the distance along the line of the eclipse between two points by the speed of the movement of the moon's shadow and the parallax of the moon was suggested by T. Banachewiecz (Poland) in 1929. The whole eclipse does not last more than 8 minutes while the shadow moves about 1 kilometer per second. By giving the astronomical coordinates of a number of points in the path of the eclipse, it is possible to calculate the times the shadow crosses these points (second and third contacts). Photographs at the beginning and end of the full phase are obtained with the aid of a coelostat on the moving-picture film at a rate of 20 frames per second [16]. The parallax of the moon in terms of right ascension is determined for observed and calculated times of full eclipse, which gives two equations for each observation

$$X_C - \xi = \sin P; \; Y_C - \eta = l \cos P, \qquad (10)$$

where l is the radius of the shadow and P is the angle of position containing three unknowns - the geocentric latitude φ', the longitude λ', and the radius vector ρ' of the point of observation in the system of the general terrestrial spheroid if we consider the coordinates of the moon to be free of systematic errors [14].

If more than three instants of full eclipse are observed per point, then it is possible to determine the corrections $\Delta\varphi'$, $\Delta\lambda'$, and $\Delta\rho'$ from the solution of $n > 3$ equations. In this case the need for gravimetric surveying would be eliminated. In practice, however, the coefficients of the equations (10) are very close for the beginning and the end of the eclipse [14].

W. Lambert suggested considering the radius vector ρ' at a determined point and the coordinates of the initial point as known quantities in the geodetic connection of points [11]. Then it would be possible to obtain the coordinates of the determined point (relative to the plumb line), since the corrections to the coordinates of the moon could be considered as constants at the time of observation of the eclipse. Then one could obtain the distance between the points in fractions of the great semiaxis from solving the inverse geodetic problem. If, on the other hand, the points were geodetically connected, it would be possible to determine the distance to the moon from observations of eclipses (π_C) [11].

Attempts were made to conduct such observations in 1936, 1945, 1948, and 1954. Twenty-seven expeditions were organized by the United States, Sweden, and others in order to observe the eclipse of 1954, but all of them were failures due to overcast weather. On the basis of observations made in 1947 in Brazil and Africa, R. Hirvonen and T. Kukkamaki obtained corrections to the coordinates of 1,775 meters and

1,640 meters with an error in the location of the moon of about 1.5 kilometers or $\delta\varphi'_{21} = 4''.2 \pm 4''.3$; $\delta\lambda'_{21} = -5''.4 \pm 5''.5$ or 206 meters $\pm$ 214 meters with an azimuth of 231 degrees ($0''.1$ in the parallax) [16].

The relief of the moon is taken into consideration more accurately in the eclipse method than in the occultation method, since it is projected on the disk of the sun over a great distance. However, it is impossible to obtain high accuracy from processing small photographs and it is impossible to obtain many pictures per second with a long-focus telescope. Eclipses which are convenient for marriage of continents are extremely rare. Thus there will be no more eclipses in the 20th century which will be convenient for connections across the Atlantic. Finally, special expeditions are needed for the observations whose success is strongly dependent upon the weather.

Therefore, H. Plachek and others (Argentina) suggested a photoelectric method for observations, and G. Sandig and K. Notar (East Germany) designed a special photometer for the eclipse of 1954 in which two rays from two halves of the sky would fall on the photocathode so that the current would be at a maximum when the shadow passed across the zenith. Such observations accurately fixed the beginning, middle, and end of the eclipse (to 0.02 seconds) even in overcast weather (with constant cloudiness) [13]. Still, observations of eclipses will scarcely be widely applied in geodesy, since eclipses are very rare, they are not repeated at the previous point, and they are strongly connected with the weather [14].

b. The method of observations of occultations of stars by the moon was suggested by G. Wattermann (Germany) in 1902 [16]. Occlusions are observed more frequently than eclipses, and at different hour angles and declinations of the moon. However, the 3 days prior to and after the first quarter of the moon are the best suited for observations; thus, in order to avoid small altitudes, it is necessary to make the observations in the spring and the summer. The most advantageous conditions for the observations are to be found in the tropics; therefore this method is applicable only for connecting Central America and South America. The limits for applying the method are about 3,000 kilometers; thus the connection of Africa with America should include the Azores [13].

After calculating the elements of occultation in points with different coordinates, one can determine graphically suitable points of observation in the path of the occlusion. Each occultation gives rise to an equation of the form

$$a\delta r + b\,\delta X + c\,\delta Y + d\,\delta Z + e\,\delta\lambda + f\,\delta\beta_{\mathbb{C}} + l_r = 0 \qquad (11)$$

where

$$X = (N + H) \cos B \cos L;$$

$$Y = (N + H) \cos B \sin L; \qquad (12)$$

$$Z = \{N(1 - e^2) + H\} \sin B,$$

and δX, δY, and δZ are coordinates of the center of the ellipsoid relative to the center of the earth [16]. If one observes occultations at two points with the same position angle, that is, the same point on the moon, then it is possible to consider $\Delta\lambda_C$ and $\Delta\beta_C$ as constants and, by taking the coordinates of one point as known quantities, to set up the difference equations

$$a_1 \delta r + b_1 \delta X_2 + c_1 \delta Y_2 + d_1 \delta Z_2 - (T_{\text{кав}} - T_{\text{прив}}) = 0 \quad (13)$$

The equations (13) are solved analytically or graphically. The relief of the moon is taken into account with the aid of an atlas of its profile. Observations of occultations are particularly interesting for groups of stars (Pleiades, Hyades) and at full lunar eclipses [14].

In 1955-1956 K. Batchlor and others made paired observations of four occultations in the Philippines and the Caroline Islands ($s \approx 1{,}000$ kilometers) with Cassegrain telescopes and photoelectric registration. Corrections of +19".4 and -43".6 with an ellipse of errors of 504 x 276 meters were obtained for the island of Palau.

Observations of occultations at points which are geodetically connected permit determining the equatorial radius of the earth and studying irregularities in its rotation. The method of occultations is inferior to the method of eclipses and photographic observations of the moon, due to the large effect of the relief of the moon, even though it does require simpler equipment. The accuracy of observation of disappearance and reappearance is not the same. The use of photographic registration of times and improvements in taking into account the relief of the moon can improve the accuracy of the method, but it is limited in respect to latitude and the number of suitable occultations is small.

c. The method of photographic observations of the moon and stars is the most promising of the three methods described here and the best for studying irregularities in the rotation of the earth. In this case observations can be made over a large arc of the orbit and the number of convenient times which can be selected is unlimited. This method permits measuring distances from the star to a large number of points on the edge of the moon, which reduces the effect of the relief of the moon (Figure 6). However, simultaneous photographing of the moon and stars is difficult, since star photography requires 10-20 seconds' exposure, in which case the image of the moon is overexposed and not clear-cut on account of its displacement. In order to eliminate this difficulty, two methods were suggested in 1954 by V. Markowitz

(United States) [12] and A. A. Mikhaylov (Pulkovo) [14]. Both methods were investigated at Pulkovo.

In Markowitz' lunar camera a smoked plane-parallel plate used to reduce the brightness of the moon is synchronously rotated about an axis parallel to the plane of the plate by a clockwork mechanism in order to compensate for the movement of the moon relative to the stars during the exposure. An objective lens with an aperture of 20-30 centimeters and a field of 2 x 2 degrees permits photographing a large number of stars, which increases the accuracy of determination of the coordinates of the center of the moon [14], [15].

The Pulkovo camera takes ordinary photographs of the stars and the moon with the use of a rapidly rotating shield. The position of the moon relative to the stars is distorted here only by random errors in refraction and the position of the photographing telescope. On the other hand, with the Markowitz method errors in the motion of the photographing telescope and the rotation of the filter lead to a one-sided expansion in the image of the moon and systematic errors [14], [15].

The coordinates of points on the edge of the moon are first determined on the photographs by references to stars (Figure 6). Then the most probable coordinates of the center of the moon are found by measurements of the distances from the center mark to points on the edge of the moon with the equations

$$\Delta X \sin P_i + \Delta Y \cos P_i + r = p_i \qquad (14)$$

According to Markowitz' data, when 10 stars were referenced to 40 points on the edge of the moon, the accuracy of the coordinates of the center of the moon was found to be about 0".2 and the accuracy of deviations from the plumb line was about 10" (300 meters). Therefore, in order to obtain an accuracy of 1" it will be necessary to complete 100 observations of 400 references each [15].

Photographic observations of the moon at suitable points will permit determination of the absolute inclination of the plumb line, the shape and dimensions of the geoid, and the general terrestrial ellipsoid. According to the Tenth Assembly of the International Association of Geodesy (Toronto, 1958) this method should be applied during the International Geophysical Year in 20 observatories throughout the world with final processing in Washington. The plan called for obtaining more than 600 photographs at each point in order to determine the corrections for the movement of the moon. The expected accuracy of the inclination of the plumb line is 1" and of the coordinates 40 meters [15]. The results of this work (1960) will be of great importance.

d. A. A. Mikhaylov believes that observing the moon is still a difficult and thankless task [14]. Differential observations of artificial earth satellites and stars is more profitable and accurate, since the parallax of a satellite is considerably greater than that of

the moon. However, the movements of a satellite are complicated and its orbit changes. Therefore it is possible to use satellites as high-altitude moving sighting targets.

A precise value of the orbit of a satellite is required for determining the distance between points. With a velocity of the satellite of 8 kilometers per second and an error in the time interval of 0.001, the error in the distance will be about 8 meters [17]. Artificial earth satellites are observed by radio engineering and optical (photographic) methods.

In radio direction finding of artificial satellites it is necessary to determine the phase difference in signals sent from the satellite to the earth on two antennas spaced at a distance of $A_1A_2 = S$ apart and to determine the direction to the satellite by the formula (Figure 7)

$$\sin \beta = \frac{PA_2}{A_1A_2} = \frac{n\lambda}{S} . \qquad (15)$$

In order to eliminate multiple values for the angles β several pairs of antennas are used in the NS and EW planes. The position of a satellite in its orbit can be determined with the aid of a radio system (Minitrack, and others) at any time of the day and in any weather with an accuracy of 30"-40", which is sufficient for many purposes [17].

In the USSR the measurement and computation of parameters of artificial earth satellites and rockets is accomplished by a radio measuring complex whose ground stations are located at different points of the USSR. Plans have been made in the United States to determine the position of a number of islands in the Pacific Ocean with the aid of artificial earth satellites. In this case the Vanguard program has been established for determining the orbits and altitudes of artificial earth satellites from geodetically defined stations and the "Betty" program for the inverse problem - that of determining the position of the islands. The expected accuracy is about 150 meters with errors in astronomical direction finding up to 1.5 kilometers [17].

Optical observations of artificial earth satellites are conducted in the USSR by the GAISh [Gosudarstvennyy astronomicheskiy institut imeni P. K. Shternberga - the P. K. Shternberg State Institute of Astronomy]. An interrupted trace of the satellite is obtained with the aid of a rotating shield (obturator), and seven to nine stars along the trace and one star close to the center of the negative are selected. The accuracy of determination of the time, with the aid of the obturator, is about 0.05 seconds (400 meters). Computations are made on a Strela-4 computer. In Alma-Ata photographic observations are conducted with a meniscus astrograph equipped with an NAFA Maksutov camera which is fitted with an oscillating plen-parallel plate, a loop oscillograph, and a printing chronograph with an accuracy

of 0.001 seconds. Referencing is accomplished with three control stars. Errors in the position of the second satellite amounted to $\pm$ 4"-6" and the third satellite $\pm$ 2"-3" [18].

Theodolites fitted with movie cameras which have an accuracy of about 3" and Bakker-Nunn telescope cameras fitted with a stroboscope are used in the United States for observing artificial earth satellites. Photographs are made with an objective lens of 500 millimeters with f = 70 - 100 millimeters on sensitive film. The obturator interrupts exposure at intervals of 0.01 seconds and gives time markers on the film with the aid of a crystal clock. At an altitude of 300 kilometers the angular velocity of an artificial satellite is about 1.3 degrees per second. Thus, when the time is fixed down to 0.001 seconds, the position of the satellite is determined down to 1-5". Photographic methods ensure determination of the coordinates and altitudes of satellites down to 10-15 meters [17].

Simultaneous observation of a satellite by two independent systems permits determining the distance between points of these systems. If we accept angular errors of $\pm$ 5" and time errors of 0.01 seconds in optical observations of artificial earth satellites, then the errors in the coordinates as determined by the system will amount to about 40 meters along x and along y.

It is impossible to use long-focus telescopes to improve the accuracy, since they require very precise training and the time of light of a satellite across the field of vision will be very short (less than 1 second). However, television cameras permit photographing objects which are moving at angular velocities 50 times greater than a satellite. Thus the use of electronics seems more promising there [17].

Determining the precession of the orbit of an artificial earth satellite for several weeks permits an accurate definition of the compression of the earth α. It was determined in 1958 by E. Buchar (Czechoslovakia). The United States Army Map Service obtained a value of the compression $\alpha = 1:298.38 \pm 0.07$ from observations of the 1958 β_2 satellite, from 26 March to 6 June 1958 and $\alpha = 1:298.0 \pm 0.03$ for the 1958 α satellite. These figures agree well with the conclusions of F. N. Krasovskiy.

By making use of the measurements of the orbit, one can determine the mean radius of the earth with the aid of Kepler's second law by means of the formula

$$\frac{V_{max}}{V_{min}} = \frac{H_{max} + R_0}{H_{min} + R_0} \qquad (16)$$

One can then determine its mass, study the distribution of mass in the earth's crust and general anomalies in the gravitational field of the earth, connect the triangulation of the western and eastern hemispheres, and determine the shape and dimensions of the triaxial earth.

Three years ago the United States Army Map Service completed many years of work on determining the equatorial radius of the earth and obtained a value of a = 6,378,260 meters, 128 meters less than the ellipsoid of Khayford and only 15 meters larger than the ellipsoid of Krasovskiy.

Therefore observations of artificial earth satellites constitute the most accurate and promising means for geodetic marriages of continents and should be extensively developed and applied.

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FIGURE APPENDIX

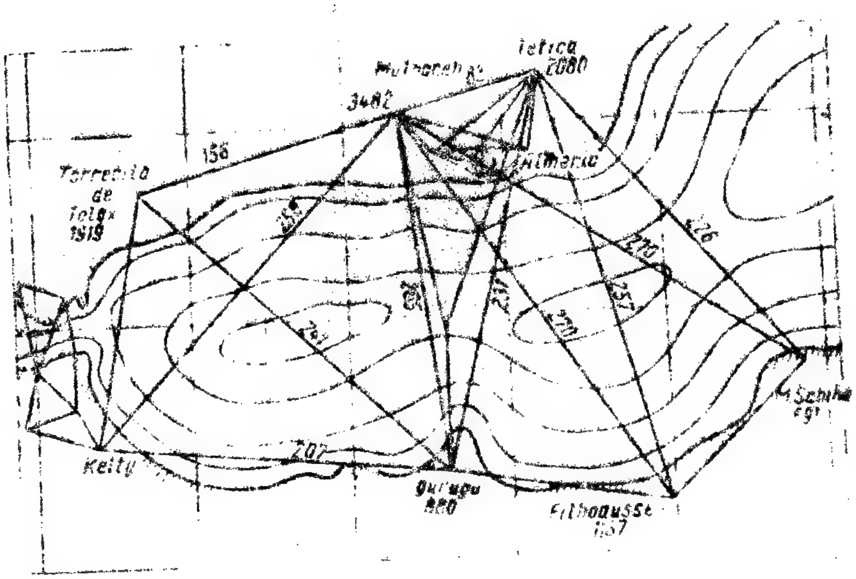


Figure 1

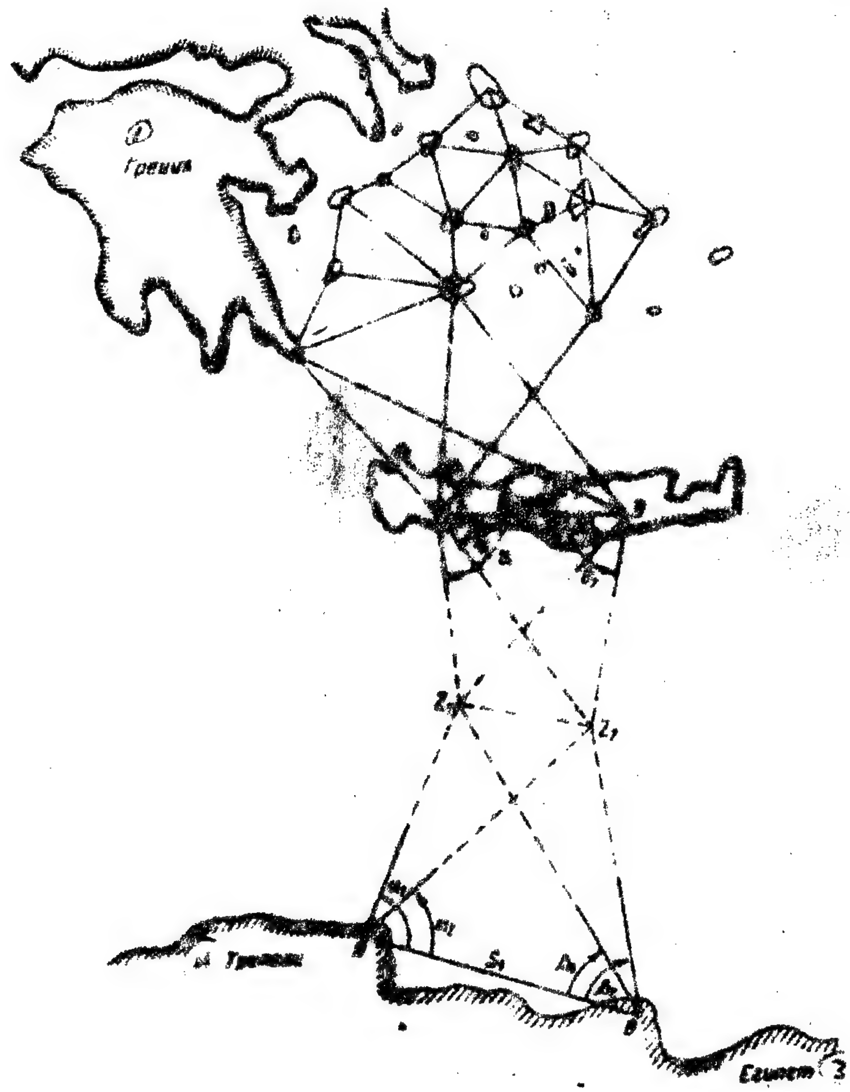


Figure 2

Legend: 1 - Greece 3 - Egypt
2 - Crete 4 - Tripoli

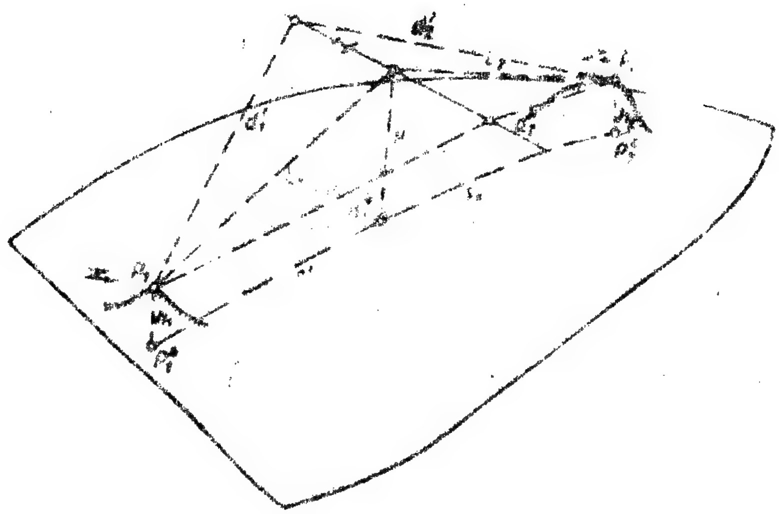


Figure 3

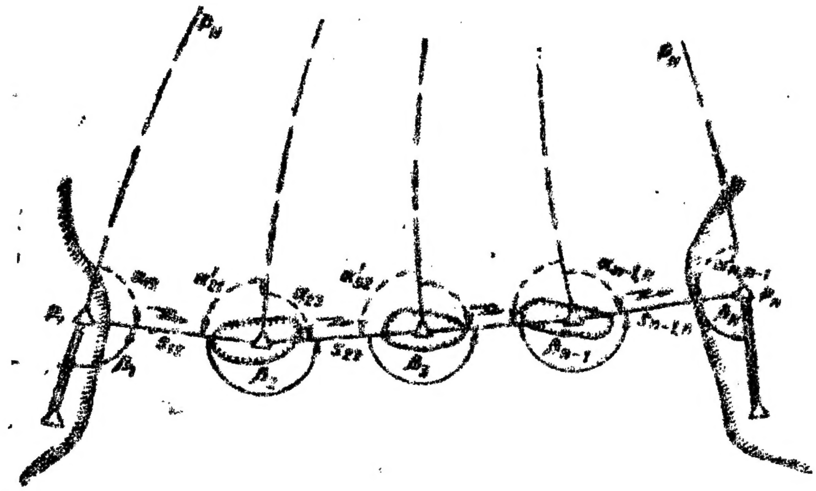


Figure 4

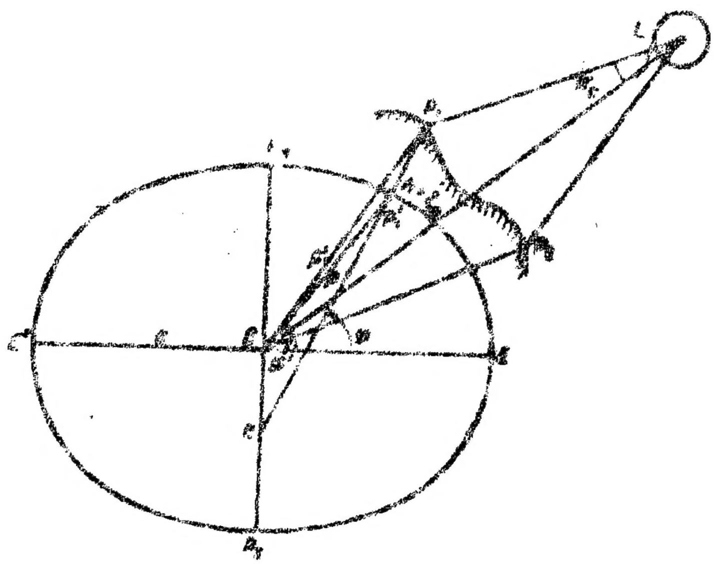


Figure 5

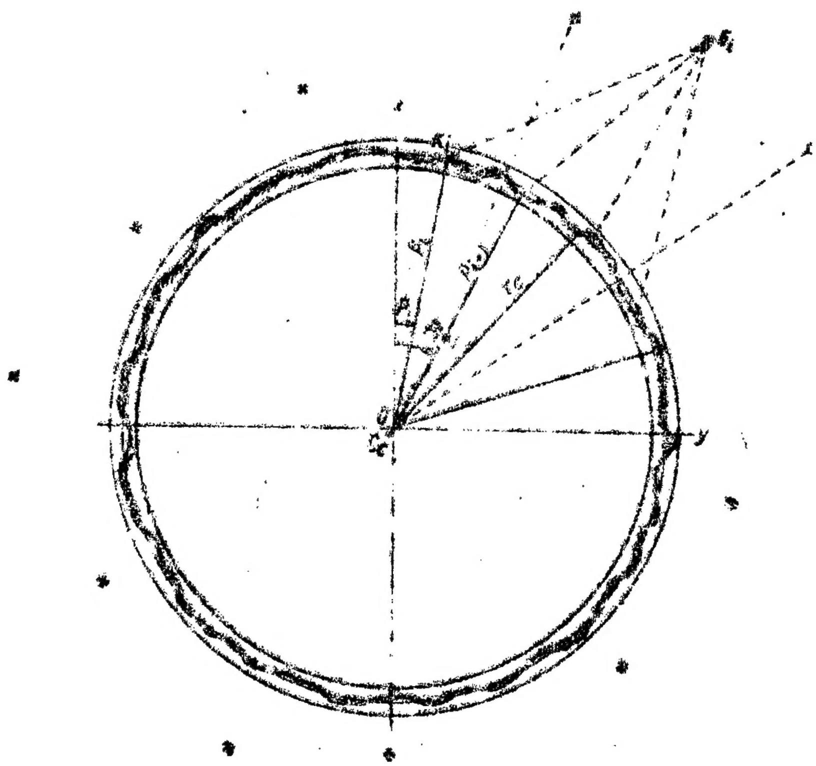
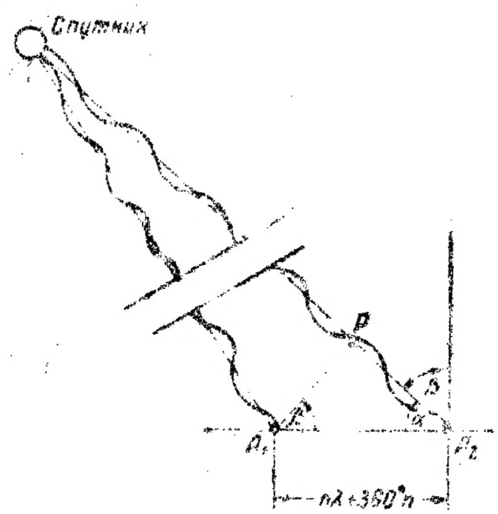


Figure 6

Satellite



A_1 A_2

$n\lambda + 360^\circ n$

Figure 7

5809

- END -